The Effect of Breakfast and Snack Consumption on Children's Cognitive Performance

Jeanet Ingwersen

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ABSTRACT

The current thesis aimed to investigate the effects of breakfast and snack on children's cognitive performance. Chapter 1 presents an overview of cognitive development followed by a review of previous literature investigating the effects of breakfast and snack consumption on cognitive performance. An overview of glycaemic index (GI) is then provided and linked to breakfast and snack intake.

Chapter 2 set out to investigate the effects of a mid-morning snack on attention and memory in children. The chapter also examines whether there were any systematic variations in cognitive performance following a mid-morning snack as a consequence of the calorific content of breakfast. Children were tested on a battery of cognitive tests 90 minutes following the consumption of an apple, banana or no snack. The results did not reveal any significant effects on any measures. Chapter 3 was the same as Chapter 2, except that attention and memory were assessed at 30 and 60 minutes post-snack rather than 90 minutes and prior breakfast intake (kcal) was changed to a covariate. The results showed a significant decline in performance from 30 to 60 minutes post-snack on a visuospatial task. However, there were no other significant results.

The main aim of Chapters 4, 5 and 6 was to investigate the effects of the glycaemic index (GI) of two breakfast cereals on children's attention and memory. Chapter 4 assessed attention and memory in children at 0, 60 and 120 minutes after the consumption of a high GI breakfast (CoCo Pops), a low GI breakfast (All Bran) or no breakfast. The results revealed a main effect of assessment time and a time x breakfast interaction on Choice Reaction Time although post hocs revealed no further significant differences. Chapter 5 set out to replicate Chapter 4 but adopted a repeated measures design and also examined if there were any differential effects of breakfast depending on the children's age. The results revealed some contradictory effects of both assessment time and of age. No other effects were found. Chapter 6 was a replication of Chapter 5 with the exception of the test battery. The test battery (CDR) employed in Chapter 6 was different from the battery in the previous chapters (CAMBA) and was considered to be more cognitively demanding and hence more sensitive to the effects of breakfast intake. The result showed some conflicting effects of assessment time and age. The results also showed a significant main effect of breakfast on Secondary Memory with better performance after the low GI cereal and an interaction between breakfast and time on Accuracy of Attention with better performance after the low GI at 180 minutes post-breakfast.

In summary, snack was not found to have any significant effects on performance. Breakfast had an effect on two measures in Chapter 6 but other than that there were no effects of breakfast. There were also some mixed findings of assessment time and age.

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AUTHORS DECLARATION

The findings from Chapter 6 have been published in a peer reviewed journal:

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Information from Chapter 1 on glucoregulation and breakfast and cognitive function has been published as a chapter in a book:

Ingwersen, J. (2012). The impact of breakfast on cognitive performance in children and adults. In L.M. Riby, M.A. Smith & J.K. Foster (Eds.), Nutrition and Cognitive Performance: A Lifespan Perspective. Palgrave Macmillan.

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Northumbria University School of Psychology and Sports Sciences Ethics Committee.

Name:

Signature:

Date:

CHAPTER 1: Introduction

1.1 Background and Overview

Although it is generally accepted that diet can affect cognitive performance, scientific investigation of the relationship between diet and cognitive function in both children and adults is a relatively new area of research. This thesis will mainly cover research in children although some studies in adults will be included where relevant. It has been suggested that diet and nutrition can have both beneficial and adverse effects on cognitive performance and behaviour (Blom-Hoffman, Kelleher, Power & Leff, 2004; Dye & Blundell, 2002; Dye, Lluch & Blundell, 2000; Hoyland, Lawton & Dye, 2008). Research has shown a reduction in behavioural problems in boys with ADHD following iron supplementation (Sever, Ashkenazi, Tyano & Weizman, 1997); effects of vitamin/mineral supplementation on attention in children (Haskell et al., 2008); links between iodine deficiency and decreased cognitive ability and motivation in children (Tiwari, Godbole, Chattopadhyay, Mandal & Mithal, 1996; Huda, Grantham-McGregor, Rahman & Tomkins, 1999); and effects of iodine supplementation on cognitive performance in iodine deficient children (Van den Briel, West, Bleichrodt, Van de Vijver, Ategbo & Hautvast, 2000). Research has, for example, shown that the symptoms of essential fatty acid (EFA) deficiency are similar to those of attention deficit hyperactivity disorder (ADHD) (Burgess, Stevens, Zhang & Peck, 2000). On the other hand, Kennedy et al. (2009)

investigated the effects of the essential fatty acid, Omega-3, on cognitive performance and mood in healthy, cognitively intact children aged 10 to 12 years of age. The authors only found significant effects of treatment on one of the many measures employed in the study, speed of word recognition. The authors interpreted this result as a chance effect and concluded that the treatment (Omega-3 supplement) did not have an effect on cognitive performance in children.

One aspect of nutrition that has received increased attention is the consumption of breakfast and mid-morning snacks and their effects on cognitive performance in children (Busch, Taylor, Kanarek & Holcomb, 2002; Benton & Jarvis, 2007; Benton & Stevens, 2008; Mahoney, Taylor, Kanarek & Samuel, 2005; Mahoney, Taylor & Kanarek, 2007; Muthayya, Thomas, Srinivasan, Rao, Kurpad, van Klinken, Owen and de Bruin, 2007; Vaisman, Voet, Akivis & Vakil, 1996; Wesnes, Pincock, Richardson, Helm & Hails, 2003; Widenhorn-Müller, Hille, Klenk & Weiland, 2008). Breakfast and snack research in children is particularly important because it is relevant to achievements in school and as stated by Gathercole, Pickering, Knight & Stegmann (2004), it is important to identify factors that can potentially enhance and predict children's achievements in school.

The current thesis reports a series of studies investigating the effects of breakfast and snack consumption on children's cognitive performance. The aim of the current chapter is to summarise previous literature in areas relevant to the thesis. This will be achieved by providing an outline of cognitive development, digestion, glucose metabolism, glycaemic index (GI) and by reviewing literature investigating the associations between glucose, GI, breakfast and snack with cognitive performance. This chapter will also identify methodological issues of previous research.

1.2. Cognitive Development

Cognition is defined as “the mental action or processes of acquiring knowledge through thought, experience and senses” in the Concise Oxford Dictionary (Oxford Dictionaries, n.d., para. 1) and is a term referring to all mental activities involved in thinking and knowing. Developmental cognitive psychology is the study of how these cognitive processes develop, mature and become more efficient and effective across the life span, with particular emphasis on children. All typically developing children follow the same developmental path although each individual developmental pattern is slightly different due to differences in biological make up and external experiences (Oakley, 2004). Studying cognition helps us to understand how different internal and external factors interact and contribute to cognitive development, with the ultimate aim of developmental cognitive psychology being to maximise children’s development (Taylor, 2005).

The development of cognition is also related to the development of the brain. Developmental cognitive neuropsychology is concerned with how the maturation of the brain is related to the development of cognitive processes (Casey et al., 2005). Most of the dramatic development of the brain and of cognitive processes happens in the first few years after birth. However, although not as obvious, maturation of the brain, which is linked to maturation of cognitive processes, is still occurring in later childhood (Sowell et al., 2002). Casey et al. (2005) reports that the areas of the brain that mature earliest are the areas that sub-serve primary processes such as sensory and motor systems, whereas the areas that mature later, like the prefrontal cortex or frontal lobe, are higher-order association areas which integrate the primary processes.

The human brain is divided into the forebrain, midbrain and the hindbrain (Pinel, 2003). Memory, attention, perception, language, emotion, planning, learning and thinking and other aspects of cognition take place in the brain and certain parts of the brain are associated with specific cognitive functions. The suggestion that there are specific regions within the brain that are domain specific for different cognitive functions is called brain modularity. The hindbrain is further divided into the Myelencephalon (medulla) and Metencephalon (pons and cerebellum) and is involved in a variety of functions such as breathing and digestion and in bodily coordination and balance. Given that damage to the cerebellum can produce cognitive deficits, it is possible that this part of the brain is also involved in cognition (Pinel, 2003). The midbrain which is also referred to as the

Mesencephalon, contains two Structures: the tectum and the tegmentum. The tectum is composed of two further structures: the superior colliculi, which is concerned with vision, and the inferior colliculi, which is involved with hearing. The tegmentum consists of grey matter, red nucleus and substantis nigra, all of which are involved in the sensorimotor system. The forebrain consists of the Diencephalon and the Telencephalon. The Diencephalon is divided into the thalamus and the hypothalamus. One of the functions of the thalamus is to process sensory information and send it to the sensory cortex. Other functions include the regulation of sleep and awareness. The hypothalamus is involved in the regulation of emotion, temperature, hunger and thirst (Pinel, 2003). The Telencephalon, which is divided into the basal ganglia, the limbic system and the cerebral cortex, is the largest section of the brain and is involved with more complex functions. The basal ganglia play a role in motor control and learning and the limbic system plays a role in the regulation of motivated behaviours such as anger and fear. The cerebral cortex is the outer layer of the brain and is involved in thinking, language, memory and attention (Pinel, 2003). There has been considerable progress in understanding the functions of the prefrontal cortex and its role in cognition. The development of the prefrontal cortex or frontal lobe allows for the regulation and planning of thought and behaviour, activities that are referred to as executive functions (Oakley, 2004). In a mature individual, executive functions enable us to plan, initiate and sustain purposeful and self-serving behaviours (Taylor, 2005).

It is usually the individual parts of cognition (e.g. delayed memory and working memory) that are being examined in a particular study and these individual parts can then be brought together to generate an explanation of larger cognitive domains (e.g. memory). Breakfast and snack studies have assessed the effects of dietary interventions on a number of cognitive domains. Ma, Hu, Gao and Bai (1999), for example, investigated the effects of energy intake (high vs low) at breakfast on a variety of cognitive domains in children. Cognitive performance was assessed in terms of addition, multiplication, number checking, logic as well as creativity and physical endurance. The authors did not find any significant effects of energy intake at breakfast on any aspect of the children's performance. Most other studies, however, have focussed on fundamental cognitive processes underlying attention and memory (e.g. Busch et al., 2002; Benton & Stevens, 2008; Cromer et al., 1990; Mahoney, 2005; Wesnes et al., 2003; Widenhorn-Müller et al., 2008). Together with executive function, attention and memory are cognitive domains that are central to children's learning and it is possible that this is the reason why attention and memory have been the focus of investigations in breakfast research. Furthermore, it is possible that attention and memory have been the focus of investigation as they are domains that are easy to conceptualise and measure.

Cognitive performance improves with age in children (Coch et al., 2007). During childhood, the pre-frontal cortex and its connections to posterior brain regions undergo substantial changes (White et al., 2002). It is possible that there is a link between changes observed in brain structure, the increase in interconnectivity and cognitive performance (Huttenlocher & Dabholkar, 1997). At the same time as the brain is undergoing these changes, research has found improvements in children's cognitive performance in both attention and working memory, which are both related to executive functioning (Klenberg, 2001). Working memory has been considered to be a vital prerequisite for executive functions such as planning and control of actions, and attention is related to executive functioning in terms of sustained attention, selective attention and arousal (Klenberg, 2001).

Gathercole (1999) reported that a number of components of memory, including short-term memory and working memory, improve throughout childhood. She stated that there is a sharp increase in spatial span (a common measure of working memory) from 4 years of age until 8 years of age. Then at 8 years this improvement is slower until about 12 years of age when it is nearing adult levels. Swanson (1999) investigated working memory in participants aged 6 years to 57 years. He examined access, storage and processing of both verbal and visuo-spatial working memory. Swanson found that performance across both verbal and visuo-spatial working memory tasks showed continuous growth and that these age-related changes were particularly related to the access and storage and not the processing of information.

Age-related changes are also observable in children's attention (Klenberg, 2001). Welsh, Pennington and Grossier (1991) reported that as early as 6 years of age, children begin to master simple visual search tasks as well as simplified three-ring versions of the Tower of Hanoi task suggesting that their planning and strategic behaviours have developed. The authors also suggested that by 10 years of age children become able to solve more complex and organise visual searches (the Matching Familiar Figures Test) and that at approximately 12 years of age, children reach adult levels of performance and are able to solve the full version of the Tower of Hanoi task. Rebok et al. (1997) investigated age related changes in attention in children aged 8 to 13 years. Measures on a range of tests such as the Continuous Performance Test, Digit Cancellation Task and the Wisconsin Card Sorting Test were taken. The authors found that there were significant improvements with age on the Continuous Performance Task, which was reflected as a decrease in errors and faster reaction time with age. They also found improved performance with age on the Digit Cancellation Task, Wisconsin Card Counting Task and the Wechsler Intelligence Scale for Children-Revised (WISC-R). In general, Rebok et al. found that improvements in children's attention developed fastest between the ages of 8 to 10 years. Between 10 to 13 years they found that such developmental changes slowed down and the improvements were more gradual at this age.

1.3. Digestion

Digestion is the process of breaking down food into smaller components that are more easily absorbed into the body. Digestion begins in the mouth where salivary amylase enzymes start to break down carbohydrates (Kalat, 2001). The digestion of fats and protein begins when food enters the stomach after travelling down the esophagus. In the stomach, food is broken down into smaller particles by hydrochloric acid and the breakdown of protein to amino acids is initiated by pepsin (Pinel, 2003). Another function of the stomach is to store the food which is then gradually released by the pyloric sphincter into the duodenum. The duodenum is part of the small intestine and most of the absorption of the digested food takes place here. Fats are emulsified by bile and transported to the lymphatic system as it cannot pass through the duodenum wall. Digestive enzymes in the duodenum break down proteins to amino acids and starch and complex sugars into simple sugars (Pinel, 2003). These amino acids and simple sugars are then absorbed into the blood stream and transported to body cells that use some of the nutrients and store the remainder as fat, protein or glycogen which can later be converted into glucose. In the large intestine water and minerals are absorbed before the remainder is passed as faeces.

1.4. Glucose

1.4.1. Glucose Metabolism

Glucose metabolism is the way in which the simple sugars in digested food are processed and used to produce energy. Once food is being digested, glucose is absorbed by the intestines and into the blood. Excess glucose is stored as glycogen in the muscles and the liver so it can be used later. Metabolism can be divided into two types of metabolic pathways; anabolic and catabolic. Anabolic is the synthesis of complex molecules from simpler molecules and catabolic is when macromolecules are broken into smaller molecules. Figure 1.1 below shows the most important pathways for energy production.

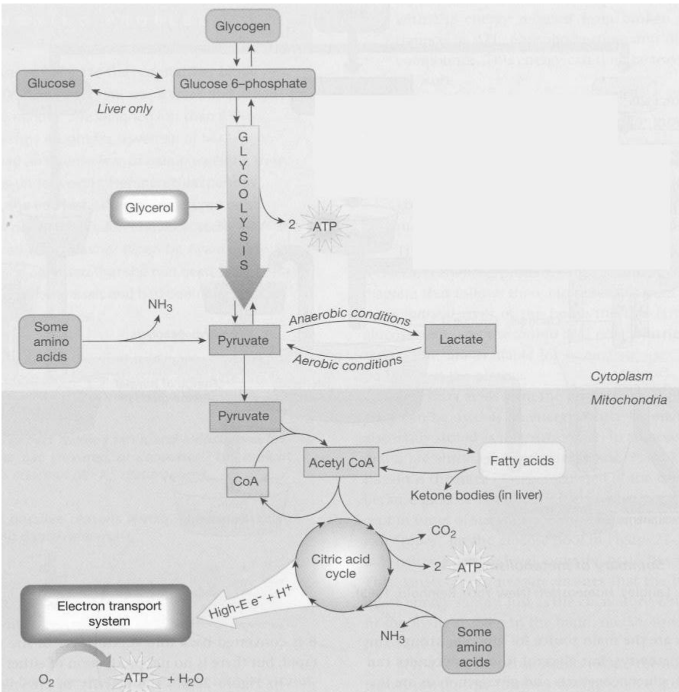


Figure 1.1: Summary of major biochemical pathways for energy production (Silverthorn, 2007).

Glucose that is not needed immediately for energy in the body goes through the anabolic pathway of glycogenesis which is the synthesis of glycogen from glucose. The first step in glycogenesis is that glucose is phosphorylated to glucose 6-phosphate by hexokinase. This is then converted to glucose 1-phosphate which is converted to uridine diphosphate glucose which is finally converted to glycogen (Tortora & Derrickson, 2009) (see Fig. 1.2). When the stored glycogen is later needed for energy the glycogen is converted back to glucose by glycogenolysis. Once stimulated by glucagon from the pantreatic alpha cells and epinephrine from the adrenal medulla, glycogen is phosphorylated to glucose 1-phosphate. This is then converted to glucose 6-phosphate which is converted into glucose (See Fig. 1.2). The glucose can then be released from the hepatocyte (liver cell) into the blood stream via glucose transporters (GluT). Only hepatocytes can release the glucose as they have phospatase. In skeletal muscle cells, when the glycogen has been broken down to glucose 1-phosphate it is catabolised via glycolysis and the Krebs cycle (Tortora & Derrickson, 2009).

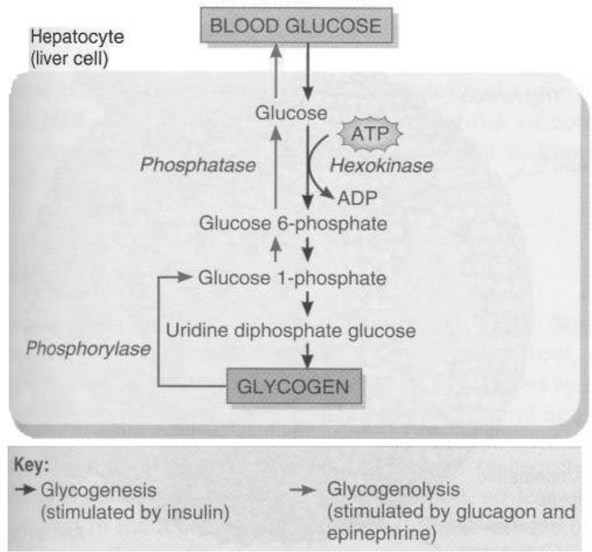


Figure 1.2: Glycogenesis (synthesis of glucose into glycogen) and glycogenolysis (breakdown of glycogen into glucose) (Tortora & Derrickson, 2009).

Glycolysis is the catabolic pathway by which glucose is broken down to pyruvate and ATP and takes place in the cytosol (intracellular fluid) (Marieb, 2012). During glycolysis glucose is first phosphorylated into glucose 6-phosphate utilising a phosphate group from an ATP molecule. This is then converted into fructose 6-phosphate and again utilising a phosphate group from ATP, fructose 6-phosphate is converted into fructose 1,6-bisphosphate. This is then converted into dihydroxyacetone phosphate and glyceraldehyde 3-phosphate (G 3-P) (each has one phosphate group). Each molecule of G 3-P then forms two molecules of NADH as two molecules of NAD^+ is oxidised accepting two pairs of electrons and hydrogen ions from two molecules of G 3-P. 1,3-bisphosphoglyceric acid (BPG) is then formed when a second phosphate group attaches to G 3-P. The enzyme phosphoglycerate kinase then transfers a phosphate group from 1,3- bisphosphoglyceric acid to ADP to form ATP and 3-phosphoglycerate. The enzyme phosphoglycerate mutase then catalyses 3-phosphoglycerate to 2-phosphoglycerate. 2-phosphoglycerate is then converted into phosphoenol pyruvate by the enzyme enolase. The final step in glycolysis is the production of pyruvate and ATP by means of the enzyme pyruvate kinase (Fig. 1.3). The first half of the glycolysis process utilises ATP to transform glucose 6-phosphate to glyceraldehyde 3-phosphate (G 3-P). The enzyme phosphofructokinase which is the enzyme that catalyses fructose 6-phosphate to fructose 1,6 bisphosphate, is the key regulator of the rate of glycolysis. When the concentration of ADP is high then the activity of phosphofructokinase is high and ATP is produced at a high rate. When the activity of phosphofructokinase is low, only some glucose enters the process of glycolysis and the rest of the glucose is converted to glycogen for storage (Tortora & Derrickson, 2009).

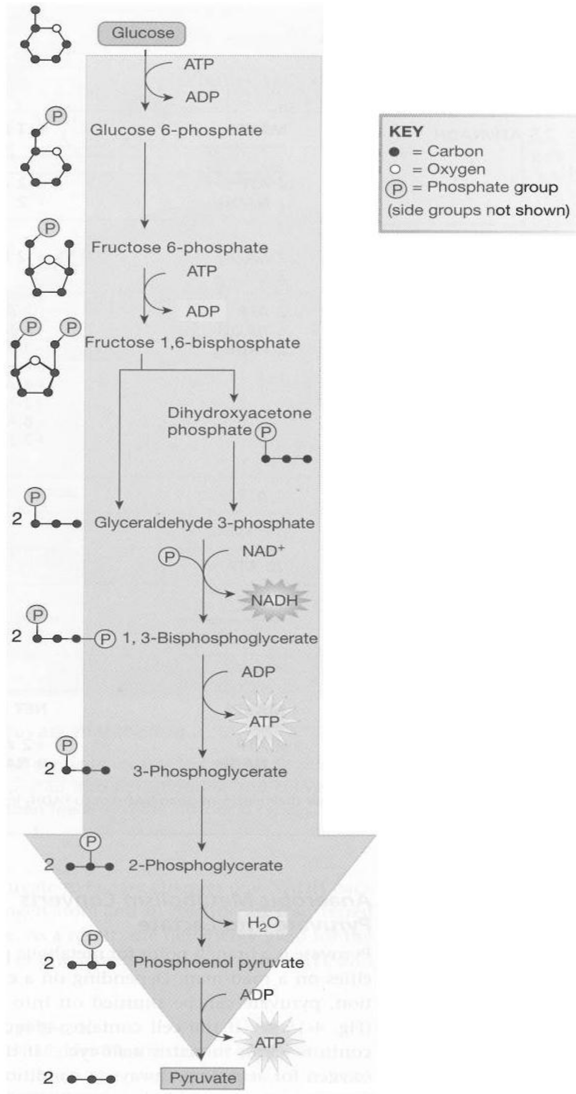


Figure 1.3: Glycolysis: catabolic pathway from glucose to pyruvate (Silverthorn, 2007).

Glycolysis, however, is not a very efficient way of ATP production; one glucose molecule forms two molecules of ATP. The low production of ATP from glycolysis is not enough to support the body's demand. A lot of the original energy in the glucose is locked in the pyruvic acid molecules. Pyruvate can follow two metabolic pathways depending on the cell's needs and state. If there is insufficient oxygen pyruvate follows an anaerobic pathway where it is converted into lactate and NAD^+ with the help of the enzyme lactate dehydrogenase. The NAD^+ is used in the oxidation of glyceraldehyde 3-phosphate and consequently the process of glycolysis continues. The lactate diffuses out of the cells and into the blood where hepatocytes removes it and converts it back to pyruvic acid (Tortora & Derrickson, 2009). If there is sufficient oxygen the pyruvate follows an aerobic pathway and is transported into the mitochondria where it enters the Krebs (citric acid) cycle (Sherwood, 1995). During the Krebs cycle ATP and carbon dioxide (CO_2) is produced (Marieb, 2012). After pyruvic acid has been transported to the mitochondria it is decarboxylated in preparation for entry to the Krebs cycle. Utilising the enzyme pyruvate dehydrogenase, pyruvate is combined with coenzyme A (CoA) to form acetylcoenzyme A (acetyl CoA). During the conversion of pyruvate to acetyl CoA, carbon dioxide (CO_2) and a molecule of NADH is produced. The acetyl CoA now enters the Krebs cycle (Fig. 1.4).

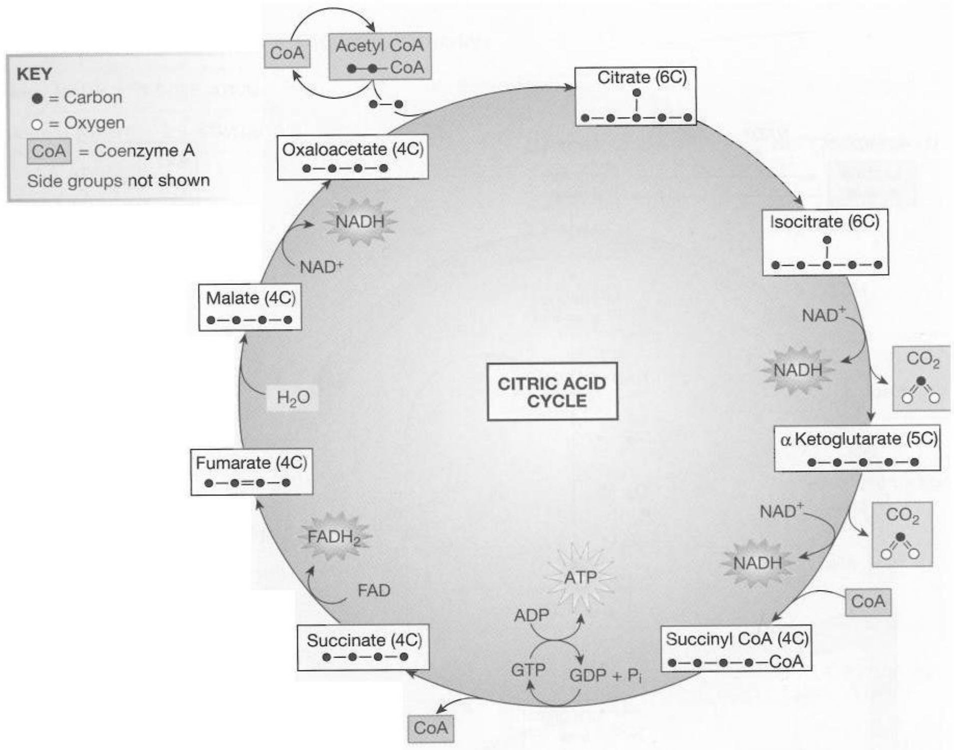


Figure 1.4: The Krebs (citric acid) cycle (Silverthorn, 2007).

The 2-carbon acetyl group of the acetyl CoA is transferred to the 4-carbon molecule oxaloacetate producing a 6-carbon molecule called citrate. The CoA molecule is released and can repeat the process of combining with pyruvate to form acetyl CoA. Citrate then undergoes isomerisation to isocitrate which then undergoes oxidative decarboxylation releasing a CO_2 molecule and NADH to form α ketoglutarate. α ketoglutarate then undergoes oxidative decarboxylation releasing a CO_2 molecule and NADH and combines with CoA to form succinyl CoA. Succinyl CoA then enters phosphorylation where CoA is displaced by a phosphate group, transferred to guanosine diphosphate (GDP) and then forms guanosine triphosphate (GTP) which can produce ATP by providing a phosphate group to ADP. The resulting succinate is oxidised to fumarate releasing $FADH_2$ which is reduced from the coenzyme flavin adenine dinucleotide (FAD). By the addition of water fumarate is converted to malate. The final step in the Krebs cycle is dehydrogeneation where malate is oxidised to form oxaloacetate and releasing NADH. The oxaloacetate can now combine with another acetyl CoA and begin the cycle again (Tortora & Derrickson, 2009).

Overall, glucose metabolism ends in the Krebs cycle with each acetyl CoA being converted to three NADH, three H^+, one $FADH_2$, one ATP and two CO_2. NADH, H^+ and $FADH_2$ enters the electron transport chain where the NADH and H^+ produces nine ATP molecules and the $FADH_2$ produces two ATP molecules. Hence, each Krebs cycle produces 12 ATP molecules from one acetyl CoA. Each glucose molecule produces two acetyl CoA, so the metabolism of one glucose molecule through the Krebs cycle and electron transport chain produces 24 molecules of ATP (Tortora & Derrickson, 2009).

1.4.2. Blood-Brain Barrier

The brain weighs only 2% of the body's weight but uses 25% of the total body glucose. The brain obtains most of its energy from the high energy phosphate adenosine triphosphate (ATP) which is produced mainly by metabolism of glucose (Zauner & Muizelaar, 1997). As previously mentioned, glucose is the product of the breakdown of food in the digestion process. During digestion glucose is absorbed into the blood and distributed to the brain cells by the bloodstream to provide energy to the brain (Raven & Johnson, 1992). For the brain to metabolise glucose the glucose must however first pass the blood-brain barrier. The blood-brain barrier is a semi-permeable barrier between the blood and the fluid that surrounds the cells of the brain. Cells of the blood vessels in the brain (central nervous system) are tightly packed and do not have gaps between them like cells in the rest of the body does and hence, many molecules, particularly protein and other large molecules, cannot pass the blood-brain barrier. Some large molecules such as glucose are therefore actively transported though the barrier by particular glucose transporters which are protein molecules (GluT) situated in the membrane (Pinel, 2003) (see section 1.4.4.).

1.4.3. Glucoregulation

Glucoregulation is the body's ability to regulate glucose levels in order to maintain glucose homeostasis. The maintenance of constant blood glucose levels is primarily regulated by the two pancreatic endocrine hormones insulin and glucagon. Insulin acts on the same cells as glucagon, but has opposite effects. Both insulin and glucagon are secreted by the islets of Langerhans (pancreatic islets) which releases hormones directly into the blood stream. Insulin is produced and secreted by the beta cells of the pancreatic islets (small islands of endocrine cells in the pancreas) and glucagon is produced and secreted by the alpha cells of the pancreatic islets (Carlson, 1999; Kalat, 2001).

Blood glucose levels rise following the uptake of glucose into the bloodstream after food intake. High levels of blood glucose levels stimulate the pancreas to release insulin into the blood. The increased levels of insulin in the blood stimulate the uptake of glucose from the blood into the cells. The glucose can then be utilised as energy though glycolysis and excess glucose is metabolized though glycogenesis where glucose is converted to glycogen and stored in the liver and muscles (Raven & Johnson, 1992). Hence, insulin plays a major role in glucose homeostasis by preventing large increases in blood-glucose concentration. In contrast, during fasting periods such as in between meals, blood glucose levels are low and the pancreas secretes glucagon into the blood. The rise in levels of glucagon in the blood stimulates glycogenolysis where stored glycogen is broken down into glucose and released into the blood with the net effect of increasing blood glucose levels (Carlson, 1999). In this way the interaction between insulin and glucoagon secretion helps to maintain constant levels of blood glucose.

1.4.4. Glucose Transportation

Before glucose can be metabolised and utilised as energy by the cells in the body glucose molecules have to be transported through the plasma membrane and enter the cytosol of cells both in the periphery and central nervous system.

Glucose absorption from the gastrointestinal tract and kidney tubules is achieved through secondary active transport (Tortora & Derrickson, 2009). Through sodium dependent glucose co-transporters (SGLT-1 in the gastrointestinal tract and SGLT-1 and SGLT-2 in the kidneys) glucose is actively transported across the membrane against the glucose gradient and into the blood. Glucose is transported using the concentration gradient of sodium between the intestine/kidneys and the blood cells. Sodium moves down its concentration gradient and brings glucose with it so that glucose and sodium are co-transported into the blood cells.

Absorption of glucose into most other cells in the body occurs via particular glucose transporters called GluT transporters. Fourteen GluT transporters have been identified. The function of some of these transporters remains to be determined although it is known that GluT 1-5 each has their specific role in glucose homeostasis (Thorens & Mueckler, 2010). GluT transporters absorb glucose into the cells via facilitated diffusion. Insulin facilitates the uptake of glucose into cells except for in neurons and hepatocytes. Following high levels of blood glucose insulin is secreted into the blood stream producing high levels of insulin which causes the translocation of GluT 4 from compartments in the intracellular membrane to the plasma membrane. The presence of GluT 4 on the plasma membrane then allows for an increased rate of facilitated diffusion of glucose into the cells where glucose metabolism can take place (McCarthy & Elmendorf, 2007).

The transfer of glucose into hepatocytes is via GluT 2 transporters and is indirectly dependent on insulin. Insulin activates hexokinase which phosphorylates glucose keeping the glucose concentration inside the cell low compared to the concentration in the blood so that the glucose continues to diffuse into the hepatocytes via the GluT2 transporters. To maintain homeostasis glucose is transported out of the heptocytes via GluT 2 transporters when insulin levels are low (Silverthorn, 2007).

Transportation of glucose into neurons happens through facilitated diffusion. As mentioned earlier, glucose must cross the blood-brain barrier. This is accomplished with the help of GluT 1 transporters which are present in the endothelial cells that line the blood vessels. In the endothelial cells the concentration of GluT 1 is three-four times higher on the surface of the abluminal (brain) side of the cells than on the luminal (blood) side (Messier, 2004). Due to this asymmetric distribution of GluT 1 transporters a concentration gradient is created that allows glucose to be diffused down the concentration gradient from the blood to the endothelial cells via the GluT 1 transporters. Glucose is then transported from the endothelial cells into the extracellular fluid in the brain where it is transported to astrocytes via GluT 1 transporters. Glucose can then be stored as glycogen. The astrocytes then releases energy back into the extracellular fluid as glucose or lactate where it is taken up by the neurons. This is the preferential way of transporting glucose to the neurons. An alternative way is a more direct way of transporting glucose from the blood to the extracellular fluid and then into the neurons via GluT 3 transporters located on the neurons where glucose is metabolised for energy (Messier, 2004).

1.5. Glucose and Cognitive Function in Children

Age related differences have been reported in cerebral glucose metabolism (Chugani, 1998). Kennedy and Sokoloff (1957) demonstrated that global cerebral blood flow in children aged 3 to 11 years was 1.8 times larger than in young adults. They also reported that children’s cerebral oxygen utilisation was 1.3 times larger than in adults. In line with such observations, Chugani (1987; 1994) reported that local cerebral metabolic rate of glucose utilisation in children aged approximately 4 to 10 years was twice as high as it was for adults. He also reported that after 9 to 10 years of age this cerebral glucose utilisation gradually decreases again until about 16-18 years of age when it reaches adult levels of utilisation. Chugani (1998) furthermore reported that the age-related changes observed in cerebral glucose utilisation in young children occur at the same time as various behaviours and cognitive skills emerge in children. Due to this higher rate of glucose metabolism in children it is possible that children are more susceptible to the effects of nutritional manipulations on cognitive performance. However, very few studies have examined the impact of glucose ingestion on cognitive performance in children. A number of studies have investigated the effects of breakfast and glycaemic load/index on children’s performance whereas studies examining the effects of a pure glucose load in children is limited.

Benton, Brett and Brain (1987) investigated the impact of glucose on cognitive performance in children aged 6-7 years. Children's ability to sustain attention was measured using the Shakow (1962) paradigm. A verbal warning was given and following a delay of either 3 or 13 seconds a light illuminated and a button press was required to measure the reaction time. There were four blocks of six trials. The first and fourth blocks had a delay of 3 seconds and the second and third blocks had a delay of 13 seconds. Children's reaction to frustration was also measured. Frustration was assessed by coding children's behaviour in response to an unfamiliar frustrating television game where a ball moving from left to right across the screen could be stopped by the child by placing an electronic bat in front of the ball. There were ten trials of 15 balls. The children's behaviours were coded as quietly concentrating, fidgeting and signs of frustration or talking. Children consumed lunch at 12.30-13.00 and received either a glucose drink (25g) or placebo at 14.30 followed by testing at 14.45-15.30. The results showed faster reaction time following glucose ingestion compared to placebo after both the 3 and 13 second delays. The authors also found that children who had the glucose drink were more likely to spend time 'quietly concentrating' and were less likely to fidget, show frustration or talk during the second half of the trials (trials 6-10). Although these results suggest that glucose may have a beneficial impact on children's cognitive performance such a conclusion should be drawn with care. The cognitive testing took place following lunch which could mean that time of the day is a factor that could have influenced the results. It also means that there were no dietary restrictions on lunch or on food and drink consumed prior to lunch.

In a subsequent cross-over study, Benton and Stevens (2008) investigated the effects of a glucose drink (25g) versus a placebo drink on children’s classroom behaviour, attention and memory. Children aged 9-10 years were tested on the Shakow paradigm (sustained attention), picture recall and spatial memory and behaviour was assessed by monitoring whether the children were on or off task during a 20 minute period when they had to solve mathematical problems. Children consumed their normal breakfast and lunch at 08.00 and 12.00, respectively. Glucose/placebo drinks were consumed at 14.15 followed by testing at 14.30. The results showed that significantly more pictures were recalled following the glucose drink compared to the placebo drink. There was, however, no effect of glucose on spatial memory or on sustained attention. The results for classroom behaviour revealed that during the last 10 minutes of observation the children spent significantly more time on task following glucose ingestion than placebo although this was not the case for the first 10 minutes. As in Benton et al’s (1987) study it should be noted that testing was done in the afternoon following habitual breakfast and lunch, hence, other factors such as time of day or differences in baseline blood glucose may have influenced the results.

Wesnes, Pincock, Richardson, Helm & Hails (2003) investigated the effects of breakfast, including glucose, in children aged 9-16 years. On four consecutive mornings children consumed glucose (38.5g), Shreddies (38.5 g CHO / 25.2g complex CHO) and Cheerios (28.7g CHO / 16.0g complex CHO). Children were assessed on a number of attention and memory tests at 09.00, 10.00, 11.00 and 12.00 with baseline measures taken at 08.00 followed by breakfast. The children fasted from 20.00 the night before. The results showed no positive effect of glucose on either attention or memory but rather showed impairments in performance following glucose compared to the other breakfasts. This study will be reviewed in further detail later in this chapter.

Some research on the effects of glucose on cognitive performance has been carried out on adolescents. Smith, Riby, Sünram-Lea, van Eekelen & Foster (2009) found that in a group of adolescents aged 13-18 years, response times during recognition memory was faster following glucose ingestion (25g) than placebo. A further study by Smith, Hii, Foster and van Eekelen (2011) found that glucose (25g) improved verbal episodic memory recall at both one hour and one week following glucose ingestion in adolescent males (14-17 years). It should, however, be noted that possible confounding variables in these studies were that they did not match the treatments on taste and that the studies were not double-blind.

Overall, it is difficult to make any firm conclusions about the effects of glucose ingestion on children's cognitive performance due to the conflicting findings, differences in methodology and possible confounding variables. As mentioned earlier, factors such as time of day and lack of dietary restrictions in previous studies can have an impact on the findings. Other factors like differences in age of participants and glucose load also makes comparison of previous studies difficult.

1.6. Glycaemic Index

There is a growing interest in the possible effects of particular foods on cognitive performance. The main macronutrients of food are carbohydrate, protein and fat. Carbohydrates are the sugars and starches found in breads, cereals, fruits, and vegetables and are the main constituent of most breakfasts (Gilsenan, de Bruin & Dye, 2009). In recent years attention has been directed towards Glycaemic Index (GI). Originally GI-research was linked to diabetes and weight control but soon started to focus on the effects of different GI foods on cognitive performance. The GI of food is defined as incremental area under the blood glucose response curve (AUC) following the ingestion of 50g available carbohydrate. The AUC of the test food is divided by the AUC of a standard reference food (usually white bread or glucose) and multiplied by 100 so the test food is expressed as a percent of the response to the reference food (Wolever, 2004; Wolever, Jenkins, Jenkins & Josse, 1991). GI is a measure of the rate at which glucose enters the bloodstream and depends upon the food consumed and the complexity of the carbohydrates. During digestion carbohydrates are broken down into simple sugars such as glucose. Glucose then enters the blood stream and is delivered to various parts of the body, including the brain. Glucose is the main source of fuel for the brain and the body's main source of glucose is carbohydrates (Benton & Parker, 1998). Carbohydrates exert their effects on blood glucose in two ways:

(1) High glycaemic index carbohydrates, also referred to as simple or quick releasing carbohydrates, typically have a GI value above 70 (see table 1.1 for example food). High glycaemic index carbohydrates are quickly converted into glucose which results in a rapid and high increase in blood glucose with a corresponding rapid decrease (see Fig. 1.5).

(2) Low glycaemic index carbohydrates, which are often referred to as complex or slow releasing carbohydrates have a GI value below 55 (see Table 1.1 for example food). As shown in Figure 1.5, low GI carbohydrates, in contrast to high GI carbohydrates, provide a smaller increase in blood glucose and a gradual decrease.

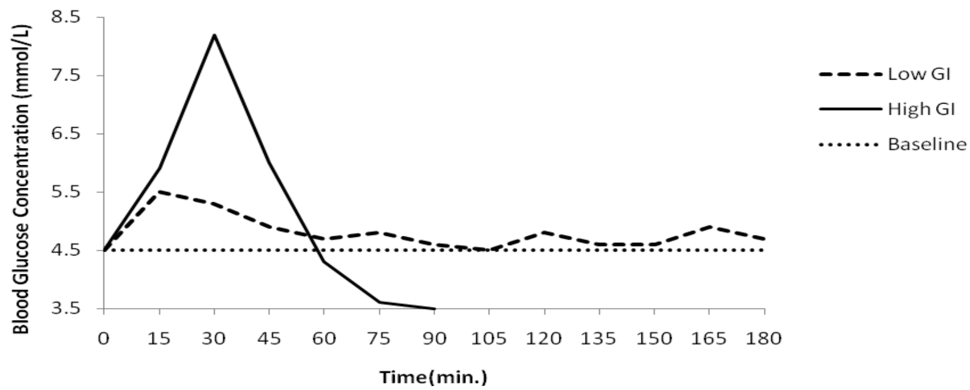


Figure 1.5: Blood glucose response after intake of high and low GI food (Ingwersen, in press).

From the graph it can be seen that both the high and the low GI carbohydrates give an immediate increase in blood glucose and hence, provide energy to the brain (Benton et al., 2003). However, approximately 60-90 minutes after consumption of high GI carbohydrates, blood sugar has fallen back down to below baseline level (Fig. 1.5), whereas after consumption of low GI carbohydrates, there is still some available blood glucose left to provide the brain with fuel over a longer period (e.g. throughout the morning).

Table 1.1: Examples of high and low GI food. The GI values are taken from an international table of glycaemic index (Foster Powell et al., 2002) and an online GI database (The University of Sydney) (adapted from Ingwersen, in press).

Category	**Examples (GI)**
High GI	Glucose (100), Boiled potato (93), White bread (70), Watermelon (80), Coco Pops cereal (77).
Low GI	Full fat milk (34), Green lentils (37), Soya beans (15), Apple (40), All Bran cereal (42).

The differences in the glycaemic response to high and low GI food are mainly related to differences in the rate at which the carbohydrates are digested and absorbed as well as the digestive/fermentation fate of carbohydrates in the small and large gut (Björck, 1996). A high GI food is digested and absorbed rapidly and increases blood glucose concentrations quickly. However, insulin is released in response to this rise in blood sugar, which, in turn, brings the blood sugar down rapidly to below baseline level. In response to the low blood glucose levels plasma levels of fatty acids increase which causes a relative insulin resistance. However, during the prolonged digestive phase associated with low GI food, the release of fatty acids is suppressed (Liljeberg, Åkerberg & Björck, 1999; Wolever, 1990).

As already mentioned the consumption of low GI food is associated with a prolonged digestive phase (reduced gastric emptying) and slower release of glucose into the blood which minimises the blood glucose response. Reduced gastric emptying and increased insulin secretion is linked to the release of peptides induced by the presence of carbohydrates in the upper gastrointestinal tract. Glucose-dependent insulinotropic peptide (GIP) is secreted in the upper part of the small intestine and glucagon-like peptide 1 (GLP-1) in the lower part of the small intestine. GLP-1 slows down the rate of gastric emptying. Hence, this could be a possible mechanism for the lower glycaemic response following a low GI food compared to a high GI food as a low GI food will have more impact on the secretion of GLP-1 (Hellström & Näslund, 2001).

Due to the lower digestibility of carbohydrates in low GI food, some of the carbohydrates do not get digested or absorbed in the small intestine and enters the colon. This increases colonic fermentation and the production of short-chain fatty acids. Although the detailed mechanism is not know yet, it seems that the production of short-chain fatty acids causes food to pass through the upper gastrointestinal tract at a slower rate which in turn might lower the absorption of starch into the blood (Thorburn, Muir & Proitto, 1993; Topping & Clifton, 2001).

The rate of glucose delivery to the blood also affects the rate of glucose availability to the brain and it has been suggested that this in turn can affect cognitive performance. Some studies, for example, have found beneficial effects of low GI food compared to high GI food on performance (for a review see Hoyland, Dye & Lawton, 2009). However, the mechanism behind this effect is not clear. The association between GI and cognitive performance and potential mechanisms will be discussed further later in this chapter.

1.6.1. Glycaemic Index, Breakfast and Snack

The relationship between blood glucose levels and cognitive performance in adults has been extensively investigated (e.g. Benton & Sargent, 1992; Kaplan et al, 2000; Martin & Benton, 1999; Sünram-Lea et al., 2002) whereas only a few studies have investigated the effect of glucose on cognitive performance in children (Benton et al., 1987; Benton and Stevens, 2008; Wesnes et al, 2003). Firm conclusions about the effects in children have yet to be made but it has been established that increased blood glucose levels have positive effects on cognitive performance in adults. However, the effect that GI has on blood glucose and consequently on cognitive performance has not been systematically investigated until recently.

The reasoning behind studies investigating the effects of GI on performance is that cognition is affected by the changes in blood glucose levels following food intake (Benton et al., 2003; Scholey, Harper & Kennedy, 2001). This is in keeping with previous research reporting that performance is enhanced after both breakfast and snack consumption compared to omission (Benton, Slater & Donohoe, 2001; Cooper, Bandelow and Nevill, 2011; Connors & Blouin, 1983). However, does the GI of breakfast and snacks influence cognitive performance differently at different times after consumption? Do high and low GI breakfasts and snacks have different effects immediately following and two hours following consumption? Referring back to Figure 1.5 it is clear that the blood glucose responses following high and low GI carbohydrates follow distinct patterns. If raised blood glucose levels are associated with enhanced cognitive performance one might expect differences in performance following the consumption of high and low GI breakfast or snack. Due to the immediate increase in blood sugar after intake of both high and low GI foods it would be expected that performance would be similar at this time point. However, after about 60 to 90 minutes one would expect that performance after the intake of the low GI food would be superior to performance after the high GI food as blood glucose levels are now higher after consumption of low GI food than after high GI food. This is due to the observation that blood glucose levels following the high GI breakfast are returning towards baseline whereas blood glucose levels following the low GI breakfast are sustained and hence, still supplying energy to the brain (Jenkins et al., 2002).

Benton et al. (2003) assessed the influence of high versus low GI breakfasts throughout the morning in adults (106 female undergraduates with a mean age of 21 years). A high or a low GI breakfast was consumed after an over-night fast and verbal memory was assessed at 30, 90, 150, and 210 minutes after breakfast. As predicted, Benton et al. found that verbal memory was better following a low rather than a high GI breakfast, particularly later in the morning at 150 and 210 minutes. Furthermore, in a second series of studies, Benton et al. (2003) also found that after a low GI breakfast-like meal, learning performance in rats was better than after a high GI meal at 180 minutes following meal consumption. The authors concluded that a low GI food is more beneficial to verbal memory than a high GI food. It is however important to note that in Benton et al.'s study, blood glucose levels had returned to baseline at the time point that memory was better after the low GI, suggesting that this results may not be due to the effects of GI.

Only one single study from the US has directly investigated the effect of breakfasts of differing GIs on cognitive processes in children. In a cross-over study, Mahoney et al. (2005) examined the effects of GI in thirty children aged 6 to 11 years. Cognitive performance was assessed by completion of a rather large (approximately 1 hour) battery of cognitive tests consisting of spatial memory, short-term memory, visual perception, visual attention, auditory attention, and verbal memory. After an overnight fast, children consumed either a low GI breakfast (oatmeal), a high GI breakfast (ready-to-eat cereal) or they received no breakfast. Over a three week period all children took part in all breakfast conditions. Breakfast was given at 8:15 to 8:30 a.m. and testing took part an hour later between 9:30 and 10:30 a.m. Overall, the results replicated previous findings suggesting that breakfast enhances cognitive performance when compared to no breakfast. More interestingly, when comparing the high and low GI breakfasts, Mahoney et al. found that girls but not boys performed better on a short-term memory task after the consumption of the low GI breakfast and that all of the younger children (girls *and* boys aged 6-8 years) additionally performed better on an auditory attention task after the low GI breakfast. However, Mahoney et al. did not find any significant effect of GI on a number of their measures. It should also be noted that there were differences in macronutrient and energy content between the two breakfasts which could present potential confounding implications for the results.

1.7. Breakfast, Snack and Cognitive Performance

1.7.1. Breakfast Consumption and Cognitive Performance

Evidence suggests that breakfast eaters of all ages tend to have a healthier diet. They tend to consume more wholesome, nutritious foods like whole grains, fruits and vegetables, whereas people who skip breakfast are more likely to eat more high-fat snacks such as crisps, chocolate, chips and carbonated drinks and consume more food at lunch time (Rampersaud, Pereira, Girard, Adams, & Metzl, 2005; Shaw, 1998). Such dietary behaviours following breakfast omission can have adverse effects on health and lead to under- or over-nutrition. Furthermore, breakfast omission has recently been associated with reduced cognitive performance (Rampersaud et al., 2005).

Some of the earliest studies examining the association between breakfast and cognitive function were the Iowa Breakfast Studies (Tuttle et al., 1949; 1950; 1952; 1954). Tuttle and colleagues carried out a series of studies investigating the effects of different breakfasts on cognitive performance, mainly in adults but also in the elderly and in children. Overall, the results from these studies indicated that that the consumption of breakfast can enhance cognitive performance. The studies have been criticised for a number of reasons such as small sample sizes and inconsistent findings. However, the results warranted further investigation and produced an increased interest in the effects of breakfast on cognitive performance which has expanded in the last few years.

Since Tuttle et al.'s studies in the late 40s and early 50s, a number of studies have found improved cognitive performance in both children and adults following the consumption of breakfast compared to the omission of breakfast (e.g. Smith et al., 1992; for review see Pollitt & Mathews, 1998). Benton and Sargent (1992), for example, investigated the effect of breakfast versus no breakfast on spatial memory and immediate word recall. Male and female participants aged 19-28 years were tested under one of two conditions (breakfast or no breakfast) after an overnight fast. The breakfast consisted of a milk-based drink named "Build Up" (Nestlé) which provided 327kcal, 37.7g CHO, 18.5g protein and 12.2g fat. Memory was tested 2 hours after breakfast/no breakfast. However, the authors don't state what time breakfast was provided. The results showed no significant difference between breakfast and no breakfast on the number of errors on either of the memory tasks. There was, however, a significant effect on reaction time for both tests in that reaction times were better after participants had consumed breakfast compared to when they had not consumed breakfast. Benton and Sargent also measured participants blood glucose and found that blood glucose was negatively correlated with performance on both memory tests and that this correlation was significant for both reaction time and errors on the spatial memory task (not the immediate recall task). Benton and Sargent concluded that their results support the suggestion that increased blood glucose levels induced by breakfast intake facilitate memory performance.

Smith, Kendrick, Maben and Salmon (1994) investigated the effect of breakfast and caffeine intake on cognitive performance as well as mood and cardiovascular functioning in two experiments (only the effect of breakfast on cognitive function will be discussed here). In Experiment 1 forty-eight male and female university students consumed one of three breakfasts (after an overnight fast): a cereal/toast breakfast (451kcal: 25g corn flakes, 150ml semi-skimmed milk, two teaspoons of sugar, one slice of wholemeal toast, 10g margarine and 25g marmalade); a cooked breakfast (451kcal: two scrambled eggs, two slices of bacon, one slice of wholemeal toast and 10g of margarine) or no breakfast. Participants carried out three sustained attention tasks: a simple reaction time task, a five-choice serial response task and a repeated digits vigilance task. The tasks took 24 minutes to complete. Participants were tested according to an early or a late schedule. In the early schedule participants' performance was tested at 8.00am, had breakfast at approximately 8.30am and were tested again at 60 minutes (9.30am) and 120 minutes (10.30am) post breakfast. In the late schedule participants were tested at 8.30am, received breakfast at 9.00am and were tested again at 60 minutes (10.00am) and 120 minutes (11.00am). The analyses showed no significant effect of breakfast on any of the measures of sustained attention. The authors considered that the lack of results could be due to insensitivity of the cognitive tests or that the breakfasts were not producing any changes in state. However, the tests were shown to be sensitive to caffeine intake and the breakfasts did produce physiological and mood changes and the authors concluded that breakfast did not have an effect on sustained attention. The authors further reasoned that although they did not find any effects on attention this did not exclude the possibility that breakfast could have an effect on other cognitive measures. Based on Benton & Sargent's (1992) study where breakfast was found to have an effect on memory, Smith et al. carried out a second experiment to investigate whether breakfast could improve memory. Forty-eight male and female students took part in Experiment 2 (none of them had taken part in Experiment 1). The cereal breakfast condition was dropped from experiment 2 leaving the cooked breakfast condition (identical to exp. 1) and the no breakfast condition. Participants completed four memory tasks lasting approximately 20 minutes: free word recall, delayed word recall, logical reasoning and semantic processing. Participants were again tested according to an early and a late schedule. For the early schedule testing started at 7.45, breakfast at 8.45am and testing again at 45 minutes (9.30am) and 105 minutes (10.30am) post breakfast. For the late schedule testing started at 8.30am, breakfast at 9.30am and testing again at 30 minutes (10.00am) and 105 minutes (11.00am) post breakfast. When reporting the results of experiment 2 the authors refer to results at 1 hour and 2 hours post breakfast. Although not strictly following their reported schedules, it is assumed that 1 hour refers to the first test session and 2 hours refers to the second test session after breakfast. For free word recall the results showed a significant effect of breakfast at 1 hour post consumption with better performance following breakfast compared to no breakfast. At 2 hours post breakfast there was a trend towards better performance following breakfast compared to no breakfast. On delayed word recall participants in the breakfast condition made significantly fewer false alarms both at 1 hour and 2 hours post breakfast. There were no other significant effects on delayed word recall. For the logical reasoning task however, participants who had consumed breakfast performed significantly worse at 2 hours than the participants who had not consumed breakfast. There were no effects at 1 hour post breakfast. For the semantic processing task there were no effects of breakfast at either time point. Overall, Smith et al. concluded that breakfast has no effect on sustained attention and that the effects on memory depend on the specific memory task that is carried out. The positive effects of breakfast on memory in Smith et al.'s study were mainly observable at 1 hour post breakfast. Given that this 1 hour post breakfast measure was a combination of the early and late schedules where performance was actually measured at 30 and 45 minutes post breakfast, this is in line with research by Vaisman et al. (1996). Vaisman et al. found that breakfast has a positive effect on cognitive performance if consumed 30 minutes prior to testing but not if consumed 2 hours prior to testing. However, in contrast to Vaisman et al., Smith et al. did find some significant effects at 2 hours post breakfast (positive effect on delayed word recognition and negative effect on logical reasoning). Smith et al.'s 2 hour post breakfast measure was actually taken at 105 minutes and it could be that breakfast still has some effect at this later time point.

More recently research has focused on the effects of breakfast in children, as this may be particularly important to school performance. Numerous studies investigating the effects of breakfast on children’s cognition have suggested that children’s cognitive performance is enhanced after eating breakfast as compared to omitting breakfast (e.g. Michaud, Musse, Nicolas & Mejean, 1991; for review see Rampersaud et al., 2005). Under controlled conditions in clinical research centres, Pollitt, Lewis, Garza and Shulman (1982/83) examined the effects of breakfast consumption on problem-solving performance. Children aged 9 to 11 participated in the no-breakfast and breakfast conditions. Breakfast was served between 8:00 and 8:30 am and testing took place between 11:15 and 11:45 am. The tests included the Matching Familiar Figure test, the Hagen Central Incidental Test and an assessment of IQ. Pollitt et al. found that breakfast omission had adverse effects on children’s problem-solving performance, reflecting findings from the adult literature and indicating that breakfast omission can negatively influence cognitive performance. More recently, Wesnes et al. (2003) investigated the effects of breakfast in children aged 9 to 16 years. On four consecutive days, the children were given a different breakfast every day. The breakfasts consisted of either Cheerios, Shreddies, a glucose drink or no breakfast. On each day the children completed the Cognitive Drug Research (CDR) Computerised Assessment Battery which consists of a series of computerised tests of attention and memory. The test battery was completed once prior to breakfast and again at 30, 90, 150 and 210 minutes after breakfast. The results showed that in the conditions where the children consumed either the glucose drink or had no breakfast, attention and episodic memory declined throughout the morning. However, for both measures this decline was significantly reduced when the children had consumed either Cheerios or Shreddies for breakfast. In line with previous research, Wesnes et al. concluded that children's cognitive performance can be positively affected by breakfast in the form of cereal, in that it reduces the decline in cognitive performance that is observed across the morning. It is, however, important to note that the two cereals used in Wesnes' et al.'s study differed in nutritional compositions, particularly in terms of carbohydrate (CHO) content. The 45g portion of Shreddies contained 38.3g CHO of which 25.2g was complex CHO, 6.9g sucrose and 6.25g lactose and the 30g portion of Cheerios contained 28.7g CHO of which 16.0g was complex CHO, 6.4g sucrose and 6.25g lactose (including 125ml semi skimmed milk for both cereals). The glucose drink contained 38.3g CHO. The authors do not report any other nutritional values of the breakfasts nor do they report any differences in cognitive performance between the two breakfast cereals. Because there is a difference in the CHO content and possibly other content of the cereals, it is possible that the two cereals could affect cognitive performance differently.

In contrast to this research, some studies do, however, suggest that breakfast consumption has no effect on cognitive performance (e.g. Cromer et al., 1990; Lopez et al., 1993). Dickie and Bender (1982) reported the results from two studies examining the effect of breakfast omission on cognitive performance in schoolchildren. In Study 1, they investigated whether there were any differences in cognitive performance between children who consumed breakfast and children who skipped breakfast. Dickie and Bender tested a group of first-year pupils (n=227; mean age 12.5 years) and a group of fourth-year pupils (n=260; mean age 15.3 years) on a letter cancellation task. Participants were divided into four conditions dependent on what they had consumed on the morning of testing: 1) breakfast + mid-morning snack, 2) breakfast + no snack, 3) no breakfast + mid-morning snack, and 4) no breakfast + no snack. Information about breakfast and snack consumption was collected via a questionnaire on the test day. Breakfast was categorised as any solid food consumed before arriving at the school on the day of testing. A mid-morning snack was categorised as any food or drink consumed at break time. At lunch time participants had either a school lunch or sandwiches. A sub-sample of participants was re-tested one week later. Children were tested before lunch at 12 noon and after lunch at 2pm. Dickie and Bender argued that any adverse effects of breakfast omission on cognitive performance would have disappeared in the 2pm test session after lunch consumption. The results showed no significant differences between the performance of breakfast eaters and non-breakfast eaters on the letter cancellation task. In Study 2 Dickie and Bender (1982) investigated the effects of breakfast versus no breakfast in two investigations. In investigation one they tested fifty-five pupils (mean age 17 years) on MAST 4 (memory and search task), MAST 6 and a simple addition test. In investigation two they tested fifty-three pupils (mean age 16.2 years) on a sentence verification task. In both investigations the participants were tested on three consecutive mornings in one week and three consecutive mornings the following week. In week 1 the participants were tested following their normal breakfast intake which was served at 7.45am. Testing was completed at 11.00-11.30am. In week 2, the control group followed the same procedure as in week 1 whereas the experimental group omitted breakfast. Dickie and Bender did not find any evidence that breakfast omission can affect cognitive performance in either investigation. Although Dickie and Bender did not find any effects of breakfast consumption / breakfast omission, conclusions from these studies should be made with care due to some methodological issues with the studies. Dickie and Bender ran their analysis on percentage change in performance. In Study 2 they calculated this change as a change in performance from one test day to the next. By doing this the cognitive measurement is confounded by a number of uncontrolled variables such as what the participant ate for the rest of the day, whether they had the same breakfast every morning or how much sleep they had. With this procedure they are not getting a real baseline measure from which to calculate change in scores. Similarly, in Study 1, participants consumed lunch which was not controlled for (i.e. participants ate either a school lunch or sandwiches); hence, the cognitive test measurements were confounded by lunch intake.

A few studies argue that the benefits of breakfast consumption on cognitive performance are only observable in undernourished children (e.g. Jacoby et al, 1996; Simeon & Grantham-McGregor, 1989; Pollitt et al., 1998). Aiming to evaluate the effects of breakfast on children's cognitive performance, Chandler et al. (1995) assessed a group of under-nourished and a group of sufficiently nourished children. The children were sampled from rural Jamaica and were aged 8 to 11 years. The study was a randomised cross-over study of breakfast and no breakfast conditions, with the cross-over occurring after two weeks. The children's performance was assessed by a battery of cognitive tests including verbal fluency, digit span, visual search, and speed of information processing. Whereas no effect of breakfast was observed in the adequately nourished children, the under-nourished children's performance on the verbal fluency task improved significantly after the consumption of breakfast compared to no breakfast. The results suggest that cognitive performance in under-nourished children could be more susceptible to the negative effects of breakfast omission than in adequately nourished children.

Lopez, de Andraca, Perales, Heresi, Castillo & Colombo (1993), however, found that breakfast does not affect cognitive performance in either under-nourished or adequately nourished children. The authors evaluated performance of short-term visual memory, problem solving and attention tasks in groups of normal, malnourished and underdeveloped children from a low socio-economic background in Chile. They found that although the underdeveloped children did show significantly lower scores on the attention task, none of the three groups were affected by the intake or omission of breakfast. Lopez et al. concluded that neither normal nor under-nourished children's cognitive performance is affected by the omission of breakfast.

Drawing definite conclusions as to whether breakfast can have an effect on cognitive performance in children is difficult due to the contradictions in the literature in terms of mixed findings and effects on different cognitive processes. The inconsistencies in the data from breakfast studies can be attributable to a variety of reasons including differences in research design, measures used, individual differences of participants and types of breakfast given. Appendix 6 provides a summary of the main characteristics of previous breakfast studies.

1.7.2. Snack Consumption and Cognitive Performance

The majority of studies investigating the effects of food on cognitive performance have focussed on the effects of breakfast. Several of these studies have focussed on the short-term effects of breakfast consumption on cognitive functioning in children. Although there have been some contradictory findings, there is a general consensus that the consumption of breakfast can have a positive effect on children's cognitive performance when compared to breakfast omission (for review, see Rampersaud et al., 2005).

The observed changes in cognitive performance following breakfast consumption have typically been attributed to postprandial changes in blood glucose levels (e.g. Benton et al., 2003). This concept is supported by research investigating the role of glucose on cognitive performance which has established that increased blood glucose levels can have a positive effect on cognitive performance in both children (Benton et al., 1987) and adults (Scholey, Harper & Kennedy, 2001; Sünram-Lea, Foster, Durlach, & Perez, 2002). Recently, however, breakfast research has developed from simply comparing breakfast consumption to breakfast omission, to comparing breakfasts with different nutrient compositions. A few of these studies have investigated whether breakfasts with differing glycaemic indices have differential effects on cognitive performance (e.g. Mahoney et al., 2005). Overall, such studies have suggested that the relationship between blood glucose and cognitive performance is not as simple as saying that increased levels of blood glucose have positive effects on cognitive performance. A high GI food produces a fast response in blood glucose characterised by a rapid increase followed by a rapid decrease in blood glucose. A low GI food on the other hand, provides more sustained levels of blood glucose and what is typically observed is a longer lasting effect on cognitive performance after the consumption of a low GI food compared to a high GI food. Hence, findings suggest that the consumption of a low GI food is more beneficial to cognitive performance than the consumption of a high GI food, particularly after a longer period of time (Benton et al., 2003; Mahoney et al., 2005).

Furthermore, a number of studies have found that the glycaemic index of a meal can affect the glycaemic response to the consumption of subsequent meals. It has particularly been suggested that a low GI meal improves glucose tolerance to subsequent meals. This is referred to as the second meal effect. Some studies that have investigated the second meal effect have examined the time interval between breakfast and lunch (e.g. Clark et al., 2006; Jenkins et al., 1982; Liljeberg et al., 1999) and some have examined the interval between an evening meal and breakfast (e.g. Axelsen, Arvidsson Lenner, Lönnroth & Smith, 1999; Axelsen, Arvidsson Lenner, Lönnroth, Taskinen & Smith, 2000; Nilsson, Granfeldt, Östman, Preston, & Björck, 2006). As discussed earlier in this chapter, the improved glucose tolerance observed in the second meal phenomenon could be due to two mechanisms; decreased postprandial insulin levels and the production of short-chain fatty acids during colonic fermentation (Liljeberg et al., 1999). It has to be noted however, that there are methodological differences between the studies examining the second meal effect in relation to glycaemic response. There are for example differences in sample populations (e.g. healthy v diabetes), test meals and the time interval between the first and second meals.

Given the improved glucose tolerance in the second meal effect and the association between cognitive performance and glucose ingestion it is possible that the second meal effect is also present in relation to cognitive performance, i.e. a low GI meal can improve cognitive performance following a subsequent meal. To date only one study has directly examined this. Lamport, Hoyle, Lawton, Mansfield & Dye (2011) investigated whether an evening meal had an effect on attention (attention switching task - AST) and memory (visual verbal learning task –VVLT & word recognition test – WRT) following the consumption of breakfast in healthy young males aged 19-28 years. In this cross-over study participants received a high GI (GI=72) and a low GI (GI=47) evening meal (both meals: 971kcal, 137g CHO, 24g fat, 60g protein) and a standardised high GI (GI=75) breakfast (732kcal, 153g CHO, 7.9g fat, 21.5g protein). Performance was tested both before and after breakfast. The results revealed a higher glycaemic response following the high GI evening meal than the low GI evening meal on the night the meal was consumed. There was also a trend towards a second meal effect on verbal recall (VVLT) with better performance following the high GI evening meal compared to the low GI meal. The results do not provide strong evidence for a cognitive second meal effect and offers no support for a glycaemic second meal effect but do however warrant further research.

Despite the growing body of research suggesting breakfast consumption can benefit children's cognitive performance (e.g. Mahoney et al., 2005; Wesnes et al., 2003) there is a paucity of research investigating whether subsequent energy intake, such as a mid-morning snack, can benefit cognitive performance. Appendix 7 provides a summary of the main characteristics of previous snack studies. A considerable part of children's total daily energy intake can come from snack consumption (Kanarek, 1997). Although snacks are generally looked upon as unhealthy due to their tendency to be high in fat and sugar, such as in chocolate bars and crisps, it should be recognised that consumption of certain snacks can improve the overall nutritional quality of children's diet and potentially enhance their cognitive performance which in turn may have a positive impact on school performance (deGraaf, 2006).

Muthayya et al. (2007) investigated the effects of a mid-morning snack on cognitive performance in low socio-economic status (SES) and high SES children aged 7 – 9 years. In a cross-over design, children were given 3 intervention meals, each providing 840kcal. The control meal consisted of a standard breakfast (340kcal), no snack, and standard lunch (500kcal). Meal intervention A consisted of a small breakfast (187kcal), a snack (153kcal) and standard lunch (500kcal). Meal intervention B consisted of a standard breakfast (340kcal), a snack (153kcal) and small lunch (347kcal). The authors did not find any effect of snack on sustained attention or on psychomotor speed. They did, however, find that for the low SES children, having a 153kcal snack resulted in a smaller decline in immediate and delayed memory following the intake of a 340kcal breakfast but not after a 187kcal breakfast.

Benton et al. (2001) investigated the influence of breakfast and a snack on memory and mood in adult females. After an overnight fast the participants were either fasted or given a 10g or 50g carbohydrate breakfast (Corn Flakes). After

90 minutes half the participants were given a 25g carbohydrate snack (Corn Flakes) and the other half received no snack. Memory and mood was assessed once prior to breakfast consumption, twice after breakfast consumption (20 and 60 minutes post breakfast) and twice after snack consumption (20 and 60 minutes post snack). The authors found that participants who consumed a snack reported better mood. Subsequent analysis revealed that this effect was dependent on previous breakfast consumption. Consumption of a large breakfast (50g) was associated with poorer mood later in the morning. However, this effect was reversed by subsequent snack consumption, therefore preventing a further decline in mood. Furthermore, Benton et al. (2001) found that, overall, participants who consumed a snack recalled more words in the word recall memory task at 20 minutes post snack than those who did not consume a snack. In addition, when performance after breakfast but before snack was analysed, it was found that participants who had consumed either of the breakfasts spent longer time trying to recall the words than participants who had consumed no breakfast. Benton et al. (2001) suggested that the participants who had consumed breakfast spent longer because they were trying harder and interpreted these results as a positive association between breakfast consumption and increased motivation.

To further investigate if children's cognitive performance is sensitive to snack manipulations depending on prior dietary control, Benton & Jarvis (2007) investigated the role of a mid-morning snack (Muesli bar) on children's ability to concentrate after the intake of a small (<150kcal), medium (150-230kcal) and a large (>230kcal) breakfast. Overall, the results did not reveal any significant differences between the consumption of a mid-morning snack and the omission of a mid-morning snack. However, when examining the children's breakfast intake prior to snack consumption, Benton and Jarvis found that if children had consumed a small breakfast (<150kcal), compared to a medium (150-230kcal) and a large (>230kcal) breakfast, they spent more time on task and were less likely to be distracted and fidgety if they had a snack than if they had no snack.

1.8. Underlying Mechanisms

The evidence in support of a cognitive-enhancing effect of breakfast and snack is somewhat equivocal. However, the majority of studies suggest that the ingestion of carbohydrate enhances cognitive performance in children (Benton & Jarvis, 2007; Benton & Stevens, 2008; Busch et al., 2002; Mahoney et al., 2005; 2007; Muthayya et al., 2007; Vaisman, 1996; Wesnes et al., 2003; Widenhorn-Müller, 2008). It is clear that children's attention and memory is somehow susceptible to dietary induced changes in blood glucose levels. The underlying mechanisms of the dietary induced enhancement of cognitive performance is however, still uncertain. Potential mechanisms could include both central and peripheral processes (Benton & Jarvis, 2007). Glucose consumption is responsible for the synthesis of serotonin, acetylcholine, noradrenaline and glutamate, all of which have all been associated with changes in cognitive performance (Benton et al., 1996; Gibson, 2007; Messier, 2004; Widenhorn-Müller, 2008). Durkin et al. (1992) investigated whether glucose ingestion enhanced acetylcholine (Ach) synthesis and release in rats. They found that rats that were injected with glucose had a significant increase in ACh content compared to rats that had been injected with placebo (saline) suggesting that glucose affects the synthesis of ACh. Similarly, Ragozzino et al. (1996) found that glucose administration in rats enhanced ACh synthesis and release resulting in improved performance on memory tests. It is argued that the mechanism behind glucose’s enhancing effect on ACh synthesis is that ACh is synthesised from Choline and Acetyl Coenzyme A and that Acetyl Choline A is obtained from glucose metabolism (Gibson, 2007; Mahoney et al., 2007; Messier, 2004).

An alternative explanation for the cognitive enhancements following glucose ingestion is that it is due to the release of insulin. The brain is sensitive to changes in both glucose and in insulin and it has been argued that the effect of glucose on cognitive performance is due to the concomitant increase in levels of insulin with levels of glucose (Park, 2001). Insulin plays a role in metabolism and in the uptake of glucose. As described earlier in this chapter, glucose enters the brain via the GLUT family of glucose transporters, including the insulin-sensitive GLUT-4. Hence the central metabolism of glucose is controlled by insulin (Park, 2001). Studies have shown that the release of insulin can affect cognitive performance in both humans and animals (Kern et al., 2001; Park et al., 2000). Park et al. (2000) investigated whether insulin can affect memory in rats. The rats were trained on a passive-avoidance task where entry into a darkened compartment was paired with electric shock. The rats received intracerebroventricular (i.c.) injections of insulin, heat-deactivated insulin or saline. They found that the rats who had received the i.c. insulin displayed an increased latency to enter the dark compartment after a 24-hour delay compared to the rats that had been injected with the heat-deactivated insulin or saline suggesting that insulin improves memory function.

Increased blood sugar levels produce a number of effects such as changes in ACh and insulin as well as serotonin and glutamate. However, the underlying mechanism by which glucose exerts its effects on cognitive performance remains unclear and it is possible that the mechanism involves a combination of underlying processes.

1.9. Confounding Variables

Research examining the association between breakfast or snacks and cognitive performance in children has employed a number of different methodologies. Some studies, for example, have evaluated the broader effects of school breakfast programs/clubs and have tended to apply a design investigating the long term effects on general scholastic achievement and behaviour (e.g. Jacoby et al., 1996). Most of the research, however, has employed methodologies aimed at investigating acute effects of breakfast and snack on cognitive function (e.g. Busch et al., 2002; Wesnes et al., 2003). Some studies have used quasi-experimental design (e.g. Dickie & Bender, 1982; Vaisman et al., 1996). The lack of random assignment of participants and lack of control for confounding variables in many studies (e.g. Dickie & Bender, 1982) reduces internal validity and makes it hard to establish causal relationships. Some studies however, have employed randomised cross-over designs (e.g. Pollitt et al., 1998; Wesnes et al., 2003), which offer better control for confounding variables.

Other factors that can influence performance under test conditions include individual differences, age, gender, previous learning, arousal, fatigue, time of day, breakfast composition and breakfast size (Hoyland et al., 2008). It is therefore not surprising that there have been discrepancies in previous research given the number and complexity of confounding factors. Every child follows a slightly different pattern of cognitive development due to biological factors and external influences (Taylor, 2005). Such factors could contribute to differences in the effect of breakfast and snack on cognition. Furthermore, younger children's cognitive processes are still developing and it might be that their cognitive abilities have an enhanced sensitivity to the effects of breakfast or snack consumption and it is essential that the appropriate age groups are subjects of investigation. Some studies have evaluated the effects in children aged 11 to 17 years (e.g. Dickie & Bender, 1982; Cromer et al., 1990; Vaisman et al., 1996). However, most studies have investigated the effects in children aged approximately 9 to 12 years (Conners & Blouin, 1983; Chandler et al., 1995; Simeon & Grantham McGregor, 1989) with many of them finding positive effects of breakfast and snack on performance. Positive effects of breakfast on cognitive performance have also been found in children aged 6 to 8 years (Mahoney et al., 2005).

The literature suggests that the relationship between consumption of breakfast or snacks and cognitive performance is complex and it may be that differences in the nutrient composition of different breakfasts and snacks may have different effects on cognitive processes. Inconsistencies in previous findings could, for example, be due to previous studies using different breakfasts or snacks. Some studies have used cooked meals (e.g. Smith et al., 1994), some have used cereals or snack bars (e.g. Benton & Jarvis, 2007; Wesnes et al., 2003) and others have used beverages (e.g. Benton & Sargent, 1992). Whether the studies have found an effect of breakfast or snack consumption or not, the use of different foods makes it difficult to compare the results across studies as nutritional composition and manipulations are different in many studies.

Furthermore, timing of both food consumption and subsequent tests vary greatly from one study to another which could be another reason for some contradictory findings. Some studies have had a three hour interval between breakfast and testing (e.g. Simeon, 1998) whereas other more controlled studies have tested children both before breakfast consumption and at hourly intervals following breakfast (e.g. Wesnes et al., 2003). Vaisman et al. (1996) specifically set out to investigate the effects of breakfast timing on cognitive performance in children aged 11 to 13 years. Children who ate breakfast at home were compared to children who were provided with breakfast in school and children who had no breakfast on performance of the logical memory subtest of the Wechsler Memory Scale, the Rey Auditory-Verbal Learning Test and the Benton Visual Retention Test. The results revealed that when children had breakfast in school, rather than at home or when they had no breakfast, their performance was significantly better. On the basis of this Vaisman et al. concluded that consumption of breakfast 2 hours before testing (children who had breakfast at home) had no effect on performance whereas breakfast 30 minutes before testing (children who had breakfast in school) markedly enhanced performance.

1.10. Rationale

Overall, the breakfast literature suggests that consumption of breakfast is better than omission of breakfast when it comes to the effects it has on cognitive performance in children. The literature on snack consumption is less conclusive and further research needs to be carried out in order to elucidate the effects of snack consumption on children's cognitive performance. It is also essential to examine whether effects on children's performance can be obtained from manipulating meal composition. In other words, does *what* a child have for breakfast or as a snack affect cognitive performance? A few studies investigating the effects of glycaemic index on performance have suggested that a low GI breakfast is more beneficial to cognitive performance than a high GI breakfast (e.g. Benton et al., 2003; Mahoney et al., 2005). However, further research needs to be carried out in order to determine the cognitive effects associated with foods of low or high GI.

The current thesis will investigate the effects of breakfast and snack consumption on children's cognitive performance. The main aim of Chapters 2 and 3 is to investigate the effects of snack consumption on cognitive performance in children. This will be achieved by examining the effects of apple, banana and no snack on a series of attention and memory tasks. The main aim of Chapters 4, 5 and 6 is to investigate the effects of breakfast with differing glycaemic indices. This will be achieved by assessing attention and memory performance following the consumption of a high GI cereal (CoCo Pops), a low GI cereal (All Bran) and breakfast omission (the latter in Chapters 4 and 5 only).

CHAPTER 2: The Effects of a Mid-Morning Snack on Children's Attention and Memory

2.1. Introduction

The majority of studies investigating the effect of food intake on cognitive performance in children have focused on the effects of breakfast consumption. Despite the mixed nature of the results from such studies, there is a growing body of research suggesting breakfast consumption can benefit children's cognitive performance (e.g. Mahoney et al., 2005; Vaisman, 1996; Wesnes et al., 2003; Widenhorn-Müller, 2008). There is, however, a paucity of research investigating whether subsequent energy intake, such as a mid-morning snack, can benefit cognitive performance (see Appendix 7 for a summary of previous snack studies). Snacks are generally looked upon as unhealthy due to their tendency to be high in fat and sugar. With growing rates of obesity, snack consumption tends to have a bad reputation (Benton & Jarvis, 2007). However, consumption of certain snacks can improve the overall nutritional quality of children's diet (deGraaf, 2006) and it is possible that it can have a positive effect on cognitive function (Muthayya et al., 2007).

Typically, children's cognitive performance declines throughout the morning and this decline can be reduced by breakfast intake. Conners & Blouin (1983) for example, found that the number of errors children aged 9-11 made on a continuous performance task increased over the morning following no breakfast (tests at 9.50am, 11.00am and 12.10pm). They also found this result to be the case following breakfast consumption; however, at each time point fewer errors were made following breakfast compared to no breakfast suggesting that breakfast intake reduced the decline in performance. Similarly, Wesnes et al. (2003) (discussed in chapter 1) found a decline in attention and memory throughout the morning in children aged 9-16 years and that this decline was reduced on some measures following consumption of breakfast cereal. Researchers examining the effects of snack on cognitive function have posed the question of whether this decline in performance observed throughout the morning can be alleviated further by the consumption of a mid-morning snack. Busch et al. (2002) examined the effect of a confectionary snack on cognitive function in 21 boys aged 9 – 12 years. In this counter-balanced cross-over study the children consumed a 25g. confectionery snack or a placebo drink after an overnight fast. The children's attention and memory was then tested 15 minutes following snack consumption. The results showed that the children's performance on a vigilance attention task was significantly better after the consumption of the confectionery snack compared to the placebo drink. However, no significant effects of snack were found for visual perception, spatial memory, verbal memory or short-term memory span.

Research investigating the effects of snack on children's cognitive performance has furthermore suggested that the effect of snack is dependent on prior breakfast intake. Benton and Jarvis (2007) found that the consumption of a

Muesli bar only exerted its effects on children's ability to attend to their school work when the children had consumed a small breakfast (<150kcal). There was no effect of snack consumption if the children had consumed a medium (150-230) or a large breakfast (>230kcal) or when the effects of snack were analysed independently of breakfast intake. Similarly, Muthayya et al. (2007) found a breakfast dependent effect of snack consumption on immediate and delayed memory in children. However, contrary to Benton and Jarvis (2007), Muthayya et al. only found significant effects of snack consumption (153kcal snack) following the consumption of a standard breakfast (340kcal) rather than a small breakfast (187kcal). The authors, however, did not find any effects of snack on sustained attention or psychomotor speed. It is also important to note that Muthayya et al.'s significant effects were only observable in low socioeconomic (SES) children and not in high SES children. Both the low and the high SES groups were recruited from schools in urban Bangladore, India. SES was assessed on the basis of parental income and by the living Standard Measure for India (Muthayya et al., 2007). Children from developing countries with a lower SES background are more likely to be nutritionally at risk which can have an impact on intellectual development and hence, cognitive performance (Benton, 2010). However, the low SES sample in Muthayya et al.'s study was not nutritionally at risk according to a medical check up during screening. Muthayya et al. suggested that the difference in performance between the low SES and the high SES groups could be due to differences in micronutrient status or alternatively that is could be due to the fact that relative to body weight, the two groups received different energy intake with the high SES group receiving about 35% less calories at each meal compared to the low SES group. This could possibly explain the lack of effects in the high SES group.

Based on the mixed findings of previous research suggesting that there might be an association between snack consumption and enhanced cognitive performance in children and that this effect might depend on previous food consumption, the current study set out to further investigate whether a mid-morning snack has an effect on children's attention and memory and whether this effect is dependent on the calorific value of breakfast consumed prior to snack consumption. More specifically, the study assessed whether the consumption of a mid-morning snack can alleviate the decline typically observed in children's cognitive performance throughout the morning (Muthayya et al., 2007; Wesnes et al., 2003). Following previous research which suggests that breakfasts with differing glycaemic indices have a different effect on cognitive performance (Benton et al., 2003; Mahoney et al., 2005) the current study also set out to explore whether mid-morning snacks with differing glycaemic indices might affect children's attention and memory differently.

Based on previous research it was hypothesised that the consumption of an apple or a banana would have a positive effect on cognitive performance compared to snack omission. It was also predicted that performance would be better after the consumption of an apple compared to a banana due to its lower

GI value (with the caveat that such an effect may be subtle because the difference between the GI values of apples and bananas is small at 38 and 52 respectively). The interaction between snack consumption and breakfast size was exploratory in nature and did not have a specific prediction due to the mixed findings in the previous literature.

2.2. Method

2.2.1. Design

The study followed a between subject design with 2 independent variables: snack and breakfast. Snack had 3 levels: apple, banana and no snack, and breakfast had 2 levels: small breakfast (less than 300 kcal) and large breakfast (equal to or over 300 kcal), with these values being derived from a median split of estimated calorific content of meals. The snack variable was the manipulated (treatment) variable whereas the breakfast variable was calculated based on participants' breakfast intake prior to snack provision. As testing took place in school a between subjects design was deemed appropriate in order to minimise the time each participating pupil was out of class / normal school routine. Baseline measurements allowed for any pre-snack differences between the groups to be identified and dealt with accordingly. The dependent variables were the scores on the cognitive tests.

2.2.2. Participants

Thirty children aged 12 to 13 years (mean age: 12 years 10 months, age range: 12 years 5 months – 13 years 3 months) were recruited from a school in the North East of England encompassing children from middle to high socio-economic backgrounds. This age group was chosen as children of this age should have reached a stage where the rate of glucose metabolism is gradually decreasing to near adult levels (Chugani, 1987; 1994). This age group was also chosen because research has suggested that there is a peak of brain growth at around 12 years of age (Epstein, 1986) when children might be more sensitive to nutritional manipulations. Finally, this age group was selected as research has suggested that both memory (Gathercole, 1999) and attention (Welsh et al., 1991) performance is nearing adult levels.

There were 21 girls (mean body mass index (BMI) = 16) and 9 boys (mean BMI = 18). There has been some examination into whether BMI is a good measure to assess obesity in children (Dietz, 1999; Malina, 1999) and it has been suggested that BMI is less sensitive than, for example measures of skin fold thickness (Malina, 1999). However, in the current study, BMI was not used as a variable but as an approximate measure of obesity and the samples of both the boys and the girls fell within the ‘normal’ range of BMI as identified by Cole et al. (2000).

Table 2.1: Number of participants (by gender) for each condition.

	Small Breakfast	**Large Breakfast**
Apple	5 (3 girls, 2 boys)	5 (4 girls, 1 boys)
Banana	5 (3 girls, 2 boys)	5 (3 girls, 2 boys)
No Snack	4 (4 girls, 0 boys)	6 (4 girls, 2 boys)

Ethics approval was granted by the Northumbria University School of Psychology and Sports Sciences Ethics Committee. The head teacher of the participating school consented to the study taking place in the school prior to its commencement. Informed consent was also obtained from the parents/guardians of the participating children and verbal consent was given from each participating child on the day of testing. All children were instructed to consume their habitual breakfast on the test day. As all children were able to read and write, they were asked to write down everything they had consumed that morning (food and drink) before testing started. The breakfast records were later entered into DietMaster to calculate macronutrient values for further analysis (see the results section for further details). The children were given stickers for taking part and the school was given a £10 Waterstones voucher as a token of appreciation.

2.2.3. Cognitive Test Battery

A test battery, Children's Attention and Memory Battery (CAMBA) was developed based on tests used in prior research and on tests from existing test batteries used with children. One test, odd-one-out, was used from the Automated Working Memory Assessment (AWMA) battery to assess visuospatial working memory performance. AWMA is a computer based assessment of working memory particularly targeted as a tool for educational professionals and psychologists to screen for working memory problems in individuals aged 4 to 22 years. Although the battery has not been employed in nutritional research before it was felt that the odd-one-out test was appropriate to use in the current study as it is sensitive to differences in performance between children. The remaining tests (simple reaction time, choice reaction time, corsi blocks and continuous attention task) in the current battery were adapted from the Cambridge Neuropsychological Test Automated Battery (CANTAB). CANTAB is a battery of cognitive tests which is standardised and validated with a normative database including child data. The battery has previously demonstrated a sensitivity to a variety of drug effects in patients (Rhodes et al., 2004), healthy populations (Townshend & Duka, 2005) and in children (Almli, Rivkin & McKinstry, 2007; Waber et al., 2007) and is regarded as a suitable tool for observing subtle cognitive changes.

In developing CAMBA for the current study, the aim was to create a battery appropriate for the assessment of children aged approximately 5 – 13 years from a range of socio-economic backgrounds. The tests have ‘game-like’ characteristics which may help in keeping the children engaged with the test battery. Furthermore, none of the tests require reading or verbal responses. CAMBA consists of five attention and memory tests which are presented in the following order: simple reaction time, choice reaction time, Corsi Blocks, continuous attention and odd-one-out. These tests were chosen as they were believed to be sensitive to nutritional changes as similar tests have been used in previous nutrition research (e.g. Busch et al., 2002; Conners & Blouin, 1983; Wesnes et al., 2003). Details of each individual task are described below. All the tests are presented on a laptop with responses recorded electronically. The entire battery takes approximately 15 minutes to complete with parallel forms presented at each test session.

2.2.3.1. Reaction Time

Simple and choice reaction time tasks are widely used cognitive tests of attention and have previously demonstrated sensitivity to the improvements and decrements seen in cognitive performance following a number of food components and dietary supplements (e.g. Tuttle et al., 1949; 1950; 1952; 1954).

2.2.3.2. Simple Reaction Time

Twenty grey squares (each square 95 x 70 pixels, screen resolution 1024 x 768) were presented one at the time in the centre of the screen with a random inter-stimuli interval between 1000 and 3000 milliseconds. The children were required to press the space bar as quickly as possible as soon as they saw a grey square. The square would disappear when the space bar was pressed. If the space bar was not pressed the square was presented on the screen for 600 milliseconds. The dependent measure was reaction time (msec.) for correct responses. Non-responses were not analysed.

2.2.3.3. Choice Reaction Time

20 pictures of a rabbit with big ears (90 x 220 pixels, screen resolution 1024 x 768) and 20 pictures of a rabbit with no ears (95 x 110 pixels, screen resolution 1024 x 768) were presented one at the time in the centre of the screen with a random inter-stimuli interval between 1000 and 3000 milliseconds. The children were required to press the red key as soon as they saw the rabbit with the ears and the blue key as soon as they saw the rabbit with no ears (keys '*z*' and '?' was marked with red and blue stickers, respectively). A reminder of which colour represented which picture was continuously displayed at the bottom of the screen. If no response was made, the picture stayed on the screen for 600

milliseconds. Percentage accuracy (max. 100% for 40 correct responses) and reaction time for correct responses (msec.) were recorded.

2.2.3.4. Corsi Blocks

The Corsi Block task is a measure of spatial working memory originally developed as a counterpart to the verbal digit span task (Milner, 1971). The Corsi Block task has been extensively used in clinical and experimental research and has frequently been used to assess spatial working memory in children (e.g. Orsini, Schiappa & Grossi, 1981), adults (e.g. Smyth & Scholey, 1992) and patients with neuropsychological deficits (e.g. Vilkki & Holst, 1989). In the current computerised version of the task 9 grey squares (95 x 95 pixels, screen resolution 1024 x 768) appeared in a set pattern on the screen (same pattern for every trial). A predetermined number of squares would change colour to black then back to grey in a random sequence and the children were required to repeat the sequence by clicking on the squares with the mouse. The sequence of illuminated blocks started at 1 and went up to 7. There were four trials of each sequence length, giving a maximum of 28 trials and hence a maximum score of 28. Cut-off point was when a child made three errors within a sequence length. The total number of correct trials was recorded.

2.2.3.5. Continuous Attention Task

The Continuous Attention Task is a measure of visual sustained attention. The task has previously been used in research investigating the effects of food on children's cognitive performance (e.g. Mahoney et al., 2005) and has demonstrated sensitivity to changes in blood glucose levels (Donohoe & Benton, 1999) and the effect of caffeine (Haskell et al., 2008). In the current version of the continuous attention task, a target sequence of two letters (Times New Roman, size 36, screen resolution 1024 x 768) was randomly selected and continuously displayed slightly up and to the right of the centre the computer screen. A series of letters (a-z, Times New Roman, size 72, screen resolution 1024 x 768) were then randomly presented, one at the time, in the centre of the screen at a rate of 100 letters, including 8 targets (i.e. 16 letters), per minute for the duration of 3 minutes. Hence, each letter was presented for 600 msec. The children were required to press the space bar when they saw the target sequence appear in the middle of the screen. For a correct response to be made the children had to respond during the 600 milliseconds that the second letter of the target sequence was present on the screen. The measures were number of hits (max. 24) and false alarms (to calculate d') and the reaction time for hits.

2.2.3.6. Odd-one-Out

This test is an adapted version of the odd-one-out test from The Automated Working Memory Assessment (AWMA) (2004) and is a measure of visuospatial working memory. As part of the AWMA, the odd-one-out task has been extensively used to assess children's visuospatial working memory to understand how memory develops and to understand the underlying structure of memory in childhood (Alloway et al., 2006). In the odd-one-out task, an image of three squares was presented in a row with a shape inside each square (Fig. 2.1) (each square was 100 x 100 pixels and each shape was approximately 80 x 80 pixels, screen resolution 1024 x 768). The child was required to correctly identify the shape which is the odd-one-out by clicking on it with the mouse. The image then disappeared from the screen.

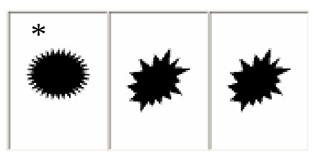


Figure. 2.1: Example of an odd-one-out shape set (* indicates correct response in this example).

A new image of three empty squares in a row was then presented and the child was required to recall the location of the odd-one-out by clicking the correct square (Fig. 2.2). The image then disappeared from the screen. A new image of a new shape set would then appear, then the blank boxes again and so on.

Figure. 2.2: Example of the odd-one-out recall phase (* indicates correct response in this example).

The number of shape sets started with 1 and increased to 7. There were four trials of each set. As the trials increased the child was required to first identify all the odd-one-out shapes in the shape sets and then recall the locations of those shapes. So, in the first set, a child would first see a shape set, identify the odd-one-out and then have to recall the location when the empty squares appeared. They would repeat this 4 times as there are 4 trials within each set. When the number of shapes sets increases to e.g. 3, the child was required to identify the odd-one-out three times and then recall the location of those three odd-one-outs (i.e. the child would first be presented with fig. 2.1 three times (a different version each time) to identify the odd-one-out and then with fig. 2.2 three times to recall the locations). This would be repeated 4 times.

The cut-off point was when a child made three errors within a block of four trials. The dependent measure was the number of trials in which the target locations were correctly recalled (max. 28).

2.2.4. Treatments

Children were randomly assigned to one of three snack conditions; apple (Granny Smith, weight ranged from 90g to 110g without the core), banana (medium ripe, weight ranged from 90g to 110g without the skin) or no snack. Although the nutritional values of apples and bananas differ, these snacks were chosen in order to keep the snacks similar to the mid-morning snacks normally provided by schools, thus allowing the findings to be applied to everyday settings. Nutritional characteristics of each treatment condition are given in Table 2.2. As the GI of bananas depends on their ripeness, medium ripe bananas were chosen in order to keep the GI as close to 52 as possible. Five to ten minutes were allowed for snack consumption.

Table 2.2: Nutritional characteristics for each snack condition. The nutritional values are taken from DietMaster (1999) and the GI values are taken from an international table of glycaemic index (Foster Powell et al., 2002). The GI values are relative to glucose as the reference food.

Nutrient	Units	Apple	Banana	No Snack
Energy	kcal	45	95	
Protein	g	0.30	1.20	n/a
Fat	g	0.10	0.30	All values=0
Fibre	g	1.70	1.10	
Carbohydrate	g	11.50	23.20	
Sugars	g	11.50	20.90	
Starch	g	Trace	2.30	
Glycaemic Index	GI	38	52	

2.2.5. Procedure

Each child was required to attend only one active study day. The children were tested in groups of twelve maximum in a quiet area of the school. Prior to testing the children were instructed to consume their habitual breakfast on the morning of the test day. Upon arrival on the test day the children were randomly allocated to a treatment group (apple, banana or no snack).

In order to familiarise the children with the tests, a practice session running through the entire test battery was carried out at 8.30am. These data were not recorded for subsequent analyses. One training session was deemed sufficient for the children to become familiar with the tasks and to avoid further disruption to class routine. The children were then required to write down everything they had consumed that morning up until that point and instructed that they were not allowed to consume anything but water until testing was finished that day. Time of food consumption prior to testing was not recorded. Pre-snack cognitive measures were taken at 10.45am. The snack was provided at 11.00am and post-snack measures were taken 90 minutes later at 12.30pm. As mentioned in chapter 1, at 90 minutes post-consumption blood glucose levels have returned to baseline levels following a high GI food but are still above baseline following a low GI food (Fig. 1.5). As the difference in GI value of apples and bananas is small, it is hoped that any potential effects of GI will be observable at this time point. Only one post-snack time point was included to keep disruption to the school and pupils to a minimum. Each test session lasted approximately 15 minutes.

2.2.6. Statistics

All data were analysed using SPSS.

2.2.6.1. Analysis of Breakfast

To create the breakfast variable in order to examine whether there were any systematic variations in cognitive performance following mid-morning snack consumption as a consequence of the size (kcal) of breakfast, the children's breakfast records were entered into DietMaster to establish approximate nutritional values of the breakfasts consumed (all food and drink consumed up until the time of testing will collectively be referred to as breakfast). Calorific values of breakfasts were calculated and using the median, the children were divided into two groups based on total calorific content provided by their breakfast intake: small breakfast (less than 300 kcal) and large breakfast (equal to or over 300 kcal). The median was used only to perform this median split and all analyses were performed on mean values generated from test scores. Separate one-way ANOVAs were carried out on each macronutrient component (kcal, CHO, sugar, fat, fibre and protein) to check for differences between the small and large breakfasts (Table 2.3 in results section). Two separate one-way

ANOVAs were then carried out on the small and large breakfasts to test for differences between the snack conditions (Table 2.4 in results section). Three separate ANOVAs were then carried out on each snack condition to see if there were any differences between the small and large breakfasts (Table 2.4. in results section).

2.2.6.2. Primary Analysis of Cognitive Outcome Measures

A one-way ANOVA was carried out on the baseline scores to test for baseline differences for each outcome measure.

Post-snack scores were analysed by a two-way ANOVA [snack (apple, banana and no snack) x breakfast (small and large)]. Both variables were between subjects variables. If significant differences were found at baseline, the baseline scores were entered as a covariate in the analysis (ANCOVA) of the post-snack scores.

Post hoc pairwise comparisons were conducted with a Bonferroni correction where there were significant differences ($p<0.05$). Where analysis revealed significant interactions further one-way ANOVAs were carried out to clarify the interactions.

2.3. Results

2.3.1. Breakfast

One-way ANOVAs on each macronutrient showed significant differences between the small and large breakfast conditions on all nutrient components. Mean nutritional values and statistics for each breakfast condition is shown in Table 2.3.

Table 2.3: Mean nutritional values of the small and large breakfasts.

Breakfast	kcal	CHO (g)	Sugar (g)	Fat (g)	Fibre (g)	Protein (g)
Small breakfast <300kcal	228.07	39.98	20.59	5.04	1.47	8.52
Large breakfast ≥300kcal	568.06	107.79	77.20	12.33	3.10	13.63
p-value	0.000	0.000	0.001	0.001	0.002	0.007

Two separate one-way ANOVAs showed no significant differences between the snack conditions on the small breakfast ($F(2,11)=2.786$; $p=0.105$) or the large breakfast ($F(2,13)=0.825$; $p=0.460$) (see Table 2.4). Further separate ANOVAs revealed significant differences between the small and the large breakfasts for Apple ($F(1,8)=18.272$; $p=0.003$), banana ($F(1,8)=22.457$; $p=0.001$) and no snack ($F(1,8)=18.967$; $p=0.002$).

Table 2.4: Mean calorie values for each snack condition by breakfast size with inferential statistics.

Breakfast	Snack			Result
	Apple	Banana	No Snack	
Small breakfast <300kcal	264.20 (31.74)	222.80 (69.25)	189.50 (23.73)	$F(2,11)=2.786$; $p=0.105$
Large breakfast ≥300kcal	566.80 (155.08)	500.40 (111.18)	625.50 (195.31)	$F(2,13)=0.825$; $p=0.460$
Result	$F(1,8)=18.272$; $p=0.003$	$F(1,8)=22.457$; $p=0.001$	$F(1,8)=18.967$; $p=0.002$	

2.3.2. Primary Analysis of Cognitive Measures

Mean pre- and post-snack scores for each snack condition by breakfast are presented in Table 2.5.

2.3.2.1. Baseline Scores

Prior to the main analysis of post-snack scores, mean pre-snack baseline scores for each outcome measure were subjected to one-way ANOVAs. There were significant differences at baseline on the simple reaction time task ($F(2,27) = 6.930$; $p = 0.004$); hence, these baseline scores were included as a covariate in the analysis (ANCOVA) of the post-snack scores. There were no other significant baseline differences for any other measures.

2.3.2.2. Simple Reaction Time

A one-way ANOVA on the pre-snack scores revealed significant differences between the snack conditions ($F(2,27) = 6.930$; $p = 0.004$). An ANCOVA (snack x breakfast) was carried on the post-snack scores with the pre-snack scores as the covariate. The results showed no significant effect of snack ($F(2,23) = 0.589$; $p = 0.563$), breakfast ($F(1,23) = 0.088$; $p = 0.769$) or significant interaction ($F(2,23) = 1.187$; $p = 0.323$).

Table 2.5: Mean scores (SD) across snack conditions and calorie group at pre-snack and 90 minutes post-snack. Significant effects and trends are indicated in the last column (Sn = snack, * trend).

Measure	Condition	n	Pre-snack	Post-snack (90 minutes)			Significant effects & Trends
			Mean	Small Breakfast (<300kcal) n=14	Large Breakfast (≥300kcal) N=16	Mean of breakfasts combined	
Simple RT (msec)	Apple	10	338.08 (52.89)	378.95 (106.83)	333.66 (7.40)	356.31 (75.28)	
	Banana	10	351.67 (34.31)	347.87 (54.96)	357.29 (72.23)	352.58 (60.71)	-
	No Snack	10	415.91 (59.22)	461.84 (88.71)	424.66 (45.40)	439.53 (64.32)	
Choice RT (% correct)	Apple	10	95.50 (2.89)	95.00 (5.86)	94.50 (3.71)	94.75 (4.63)	
	Banana	10	94.75 (2.99)	93.50 (6.02)	95.50 (4.11)	94.50 (4.97)	-
	No Snack	10	95.25 (4.78)	91.25 (15.88)	93.33 (4.38)	92.50 (9.79)	
Choice RT (msec for correct responses)	Apple	10	581.73 (147.27)	539.14 (144.98)	573.62 (101.89)	556.38 (119.52)	
	Banana	10	538.40 (63.71)	492.40 (69.77)	566.55 (69.01)	529.47 (76.21)	Sn*
	No Snack	10	631.57 (115.91)	680.51 (182.66)	633.48 (167.81)	652.29 (165.40)	
Corsi Blocks (no. correct)	Apple	10	19.10 (2.60)	19.00 (4.69)	19.60 (4.98)	19.30 (4.57)	
	Banana	10	19.30 (1.06)	19.60 (4.67)	17.60 (2.19)	18.60 (3.60)	-
	No Snack	10	19.60 (3.24)	19.00 (3.16)	20.17 (4.49)	19.70 (3.86)	
Continuous Attention (RT msec)	Apple	10	328.71 (48.52)	344.54 (74.17)	285.78 (63.94)	315.16 (72.26)	
	Banana	10	348.56 (50.61)	346.78 (59.79)	344.39 (41.97)	345.58 (48.72)	-
	No Snack	10	364.67 (54.36)	350.90 (107.01)	379.72 (34.42)	368.19 (68.53)	
Continuous Attention (d')	Apple	10	3.83 (1.04)	3.96 (1.39)	3.99 (0.59)	3.98 (1.01)	
	Banana	10	4.42 (1.25)	4.28 (1.20)	4.70 (1.05)	4.49 (1.09)	-
	No Snack	10	4.16 (1.24)	2.84 (0.96)	4.01 (0.93)	3.54 (1.07)	
Odd-one-Out Recall (no. correct)	Apple	10	20.10 (4.07)	18.60 (3.21)	19.80 (5.17)	19.20 (4.10)	
	Banana	10	19.10 (3.21)	20.80 (4.60)	18.60 (2.07)	19.70 (3.56)	-
	No Snack	10	18.30 (4.69)	17.25 (3.78)	20.17 (4.62)	19.00 (4.35)	

2.3.2.3. Choice Reaction Time

2.3.2.3.1. Percentage correct responses

Analysis showed no significant differences between the snack conditions on the pre-snack scores ($F(2,27) = 0.110$; $p = 0.896$). Further ANOVA on the post-snack scores showed no significant differences between the snack conditions ($F(2,24) = 0.340$; $p = 0.715$), the breakfast conditions ($F(1,24) = 0.201$; $p = 0.658$) or any significant interaction ($F(2,24) = 0.102$; $p = 0.903$).

2.3.2.3.2. Reaction time for correct responses

Pre-snack analysis revealed no significant differences between the snack conditions ($F(2,27) = 1.664$; $p = 0.208$). Analysis on the post-snack scores showed no significant effect of breakfast ($F(1,24) = 0.185$; $p = 0.671$) and no significant interaction ($F(2,24) = 0.552$; $p = 0.583$). There was, however, a trend for an effect of snack ($F(2,24) = 2.608$; $p = 0.094$) with better performance after consumption of banana (529.47 msec) and apple (556.38 msec) than after no snack (652.29 msec). However, this trend disappeared with further pairwise comparisons (apple – no snack, $p = 0.298$; banana – no snack, $p = 0.120$; apple – banana, $p = 1.000$).

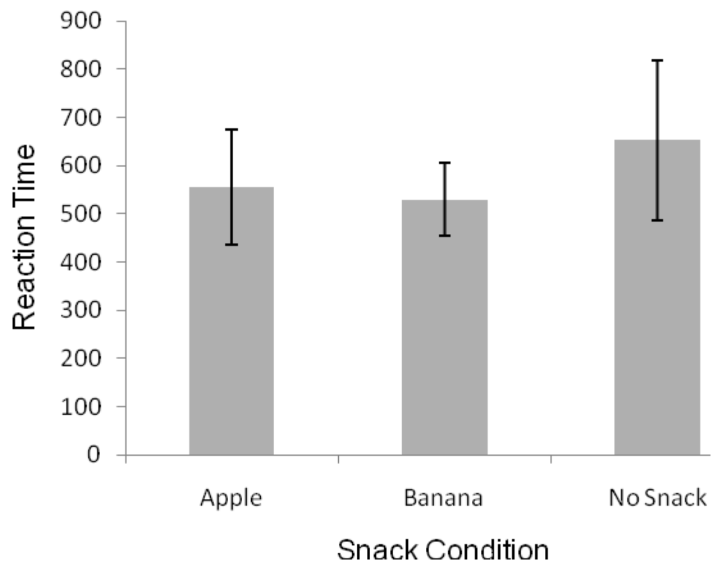


Figure 2.3: Performance on Choice Reaction Time test for the apple, banana and no snack conditions.

2.3.2.4. Corsi Blocks

The differences between the snack conditions were not statistically significant on the pre-snack scores ($F(2,27) = 0.103$; $p = 0.902$). Further analysis showed no significant effect of snack ($F(2,24) = 0.143$; $p = 0.868$), breakfast ($F(1,24) = 0.003$; $p = 0.960$) or significant interaction ($F(2,24) = 0.399$; $p = 0.676$).

2.3.2.5. Continuous Attention Task

2.3.2.5.1. Reaction Time for hits

There were no significant effects on the pre-snack scores ($F(2,27) = 1.237$; $p = 0.306$). On the post-snack scores analysis did not show any significant differences between snack (*F*(2,24) = 1.506; *p* = 0.242), breakfast (*F*(1,24) = 0.206; *p* = 0.654) or any significant interaction (*F*(2,24) = 1.163; *p* = 0.329).

2.3.2.5.2. d'

The results revealed no significant differences between the snack conditions on the pre-snack scores (*F*(2,27) = 0.619; *p* = 0.546). Analysis on the post-snack scores showed no significant differences between the snack conditions (*F*(2,24) = 2.524; *p* = 0.101), the breakfast conditions (*F*(1,24) = 1.946; *p* = 0.176) or significant interaction (*F*(2,24) = 0.737; *p* = 0.489).

2.3.2.6. Odd-one-Out

The results showed no significant differences between the snack conditions on the pre-snack scores (*F*(2,27) = 0.499; *p* = 0.613). Further analysis on the post-snack scores showed no significant effect of snack (*F*(2,24) = 0.145; *p* = 0.866), breakfast (*F*(1,24) = 0.181; *p* = 0.674) or significant interaction (*F*(2,24) = 1.002; *p* = 0.382).

2.4. Discussion

The present study investigated the effects of a mid-morning snack on children's cognitive performance. The study also examined whether any effects of snack were dependent on whether a small (<300kcal) or a large (≥300kcal) breakfast had been consumed prior to the snack and additionally explored whether there were any differences between the snacks depending on their GI. Based on previous research suggesting that carbohydrate consumption raises blood sugar, which in turn facilitates cognitive performance (Benton et al., 2003) it was hypothesised in the current study that the consumption of an apple or a banana would have a positive effect on cognitive performance compared to snack omission. It was also predicted that performance would be higher after the consumption of an apple compared to a banana due to its lower GI value. However, as the difference between the GI values of apple and banana is subtle (38 and 52, respectively), it was recognised that such an effect may not be detectable. The interaction between snack consumption and breakfast size did not have a specific prediction due to the mixed findings in the previous literature.

The results of the current study did not support the hypotheses and did not find any interactions between snack consumption and breakfast size. Although there was a trend towards better reaction time on Choice RT for the children in the snack conditions compared to the no snack condition, the results showed no significant effect of a mid-morning snack, breakfast or interaction between the two.

These results differ from previous studies by Busch et al. (2002), Benton & Jarvis (2007) and Muthayya et al. (2007). Busch et al. (2002) found that children's attention was better after snack consumption than after placebo.

Muthayya et al. (2007) found a positive effect of snack consumption in children from a low socio-economic background when the children had consumed a standard breakfast (340kcal) whereas Benton & Jarvis (2007) found that children spent more time concentrating on their work when they had consumed a snack following a small breakfast (<150kcal).

Another issue in the current study is that the size of breakfast in the small breakfast group was actually of similar calorific value to larger breakfasts in other studies (Benton & Jarvis, 2007; Muthayya et al., 2007). The reasons for this are unclear but arose from the median splits of breakfast calorific values. Although this has the value of maintaining some level of ecological validity, clearly, in order to make direct comparisons with other studies, it would be preferable to provide breakfast in order to better control calorific values and macronutrient content.

The significant effects found by Benton & Jarvis (2007) and Muthayya et al. (2007) were observed with relatively short intervals between snack consumption and cognitive testing (30 minutes). One possible explanation for the lack of significant results in the current study may be that the time interval between snack consumption and cognitive testing was too long for any effects to be detected. In the present study, children's attention and memory was tested at 90 minutes following snack consumption. 90 minutes was chosen with the prospect of finding differences in performance after apple and banana in addition to snack versus no snack as at 90 minutes (see Fig. 1.5) blood glucose might still be available after the lower GI snack (apple) compared to the higher GI snack (banana). Furthermore, Benton and Sergeant (1992) found that memory was correlated with blood glucose levels even 120 minutes after breakfast intake. The composition of the breakfast in Benton and Sergeant's study was, however, very different from the snacks provided in the current study. Their breakfast, which was a “Build Up” (Nestlé) drink, provided 327kcal, 37.7g CHO, 18.5g protein and 12.2g fat which is much higher on all components compared to the snacks in the current study. It might be that the amount of carbohydrate present in apples and bananas (see Table 2.1) is not enough to sustain blood sugar levels for such a long period of time and, hence, the blood glucose concentrations induced by the consumption of either apple or banana could have returned to baseline at 90 minutes. Consequently, it is likely that the carbohydrate intake associated with the consumption of apples and bananas is inadequate to sufficiently raise blood sugar levels enough to detect any effects on cognitive performance at 90 minutes post-snack. Further investigation should examine whether there could be any effects of snack within a shorter time period.

Vaisman et al. (1996) investigated the effects of the timing of breakfast on cognitive performance in children aged 11-13 years. 569 girls and boys participated in this 15-day study. For 14 days, two-thirds of the children received 30g. of sugared corn flakes with 200 ml. milk (3% fat) in school between 8:00

and 8:20 am. The remaining third of the children did not receive any particular instructions regarding breakfast consumption and acted as controls. These children were split into children who had not eaten breakfast and children who had eaten breakfast at home approximately 2 hours before testing (8.55 am – 9.35 am). Prior to intervention only minor differences were observed in cognitive performance between the two groups. On day 15 all the children were tested again and these scores were compared to their baseline scores. The results suggested that the children who consumed the breakfast at school performed significantly better than both the children who had eaten breakfast at home and the children who had no breakfast. Vaisman et al. (1996) concluded that breakfast can enhance cognitive performance if the interval between consumption and testing is short (30 min.) whereas if the interval is long (2 hours) this effect disappears.

Given that previous studies have found that snack consumption can have a positive effect on cognitive performance when the time interval has been shorter between consumption and testing (e.g. Benton & Jarvis, 2007; 30 min. interval) than what was the case in the current study, further research into the timing of snack consumption and subsequent cognitive testing is warranted.

CHAPTER 3: The effects of Mid-Morning Snack Consumption on Children's Cognitive Performance, the Interaction with Breakfast and the Role of Test Time.

3.1. Introduction

Although the findings from previous literature on the effects of dietary manipulations on cognitive performance in children have been mixed, a positive link between the two is increasingly being reported. Of particular interest to the current study, research has been carried out to investigate whether there are any post-prandial effects of snack consumption on cognitive performance. Although positive effects of snack on cognitive performance have been found (E.g. Busch et al. 2002), these results seem to be rather mixed. Some studies have found that the effects of snack depend on the caloric size of the breakfast consumed prior to the snack (Benton & Jarvis, 2007; Muthayya et al., 2007). These studies, however, are contradictory in whether the effect of snack is present after a small or a large breakfast. Benton & Jarvis (2007) found that children who consumed a snack in the form of a Muesli bar (226 kcal; 35g CHO) spent more time on task and were less likely to be distracted and fidgety when they had consumed a small breakfast (<150kcal) compared to a medium (150-230kcal) and a large (>230kcal) breakfast prior to snack consumption. However, Muthayya et al. (2007) found that a snack (153kcal) only had an effect on children's performance after a standard 340kcal breakfast and not after a small

187kcal breakfast. Adding to the mixed findings, Muthayya et al. found that the effect of a snack following a standard breakfast was only present in children from a low socioeconomic (SES) background and not in children from a high SES background. Benton and Jarvis (2007) did not report the SES of their sample so no direct comparison can be made here. Also, Muthayya et al. (2007) found no effects on attention or psychomotor speed but a significant effect on memory, whereas Benton and Jarvis (2007) found effects on children's concentration (e.g. time spent on task). Furthermore, the results from Chapter 2 showed no effect of snack on either attention or memory or an interaction of snack with breakfast.

One possible explanation of the lack of significant results in Chapter 2 is that an effect of snack or interaction between snack and breakfast does not exist. An alternative interpretation is that the lack of significant results could be due to the time duration between snack consumption and test time. The time elapsed from snack consumption to testing was 90 minutes and the results showed no effect of snack on either attention or memory. Benton & Jarvis (2007) and Muthayya et al. (2007) both had a time duration of 30 minutes between snack consumption and testing and they did find effects on different cognitive domains. However, Benton and Jarvis (2007) and Muthayya et al. (2007) only found effects of snack when breakfast was taken into consideration. Hence, it could be that the non-significant results in Chapter 2 are due to the time duration between breakfast and testing rather than between snack and testing. Muthayya et al. provided the children with a set breakfast at school and their schedule gave a time duration of 2½ hours between breakfast consumption and cognitive testing. Benton and Jarvis did not provide the children with breakfast. Instead, the children consumed their habitual breakfast at home before coming to school. Consequently, only an estimate can be made to the timing between breakfast and testing as the children could potentially have eaten their breakfast at any time. If breakfast was consumed at approximately 8.00am then this gives a time duration of 3 hours and 15 minutes between breakfast and cognitive testing. Similar to Benton and Jarvis (2007), the children who took part in Chapter 2 consumed their habitual breakfast before coming to school. Again, if it is estimated that the children had their breakfast at approximately 8.00am, this results in a time duration of 4½ hours between breakfast and testing. So, in Chapter 2, not only is the time duration between snack and testing longer than previous studies (90 minutes) but so is the duration between breakfast and testing (4½ hours).

Vaisman et al. (1996) investigated the effect of breakfast timing on cognitive performance in children aged 11-13 years. Children from various socio-economic backgrounds were tested twice (baseline and post intervention) on the Rey Auditory-Verbal Learning Test, the logical memory subtest of the revised Wechsler Memory Scale, and the Benton Visual Retention Test. Two thirds of the participating children were given 30g of sugared corn flakes with 200ml milk every morning, in school, for 14 days. The remaining one third of the children did not receive any instructions with regards to breakfast. At the end of the 14 days the post intervention testing took place. On this day, 66% of the children who had not received any instructions had consumed breakfast at home prior to testing. So, at post intervention testing in the Vaisman study, children were allocated to one of three conditions: children who had eaten breakfast at school, children who had eaten breakfast at home and children who had not eaten any breakfast. Vaisman et al. (1996) found significant differences between the children who had breakfast at school and children who had breakfast at home or had no breakfast on nearly all measures (8 out of 10 sub tests). Vaisman et al.'s results indicate that children who habitually eat breakfast at home do not perform better than children who skip breakfast when tested 1½ - 2 hours after consumption. On the other hand, the children who had breakfast at school approximately 30 minutes before testing outperformed both children who had eaten at home and children who had skipped breakfast leading Vaisman et al. to suggest that timing of breakfast is an important factor to consider with respect to cognitive performance.

The present study set out to investigate whether the consumption of a mid-morning snack in the form of an apple or a banana has an effect on children's memory and attention. The study also set out to explore whether the differences in glycaemic index (GI) of the snacks might affect cognitive performance in different ways. It was predicted that the consumption of either of the snacks (apple or a banana) would have a positive effect on cognitive performance compared to snack omission. It was also predicted that cognitive performance would be better after the consumption of an apple compared to a banana, particularly at 60 (compared with 30) minutes post-snack, due to its lower GI value. However, as in the previous study (Chapter 2), it is recognised that an effect of GI may not be detectable because the difference between the GI values of apple and banana is subtle (38 and 52, respectively).

3.2. Method

3.2.1. Design

The design was a 3 (snack) x 2 (assessment time) mixed measures design. Snack was a between subjects variable with 3 levels: apple, banana and no snack. Assessment Time was a within subjects variable with 2 levels: 30 and 60 minutes post-snack. Participants were randomly assigned to a snack condition. The dependent variable was the scores on the cognitive tests.

3.2.2. Participants

Thirty-seven children aged 12 to 13 years (mean age: 12 years 11 months, range: 12 years 3 months – 13 years 10 months) were recruited from schools in the North East of England encompassing children from a range of socio-economic backgrounds. This age group was chosen to keep it the same as in chapter 2. There were 16 girls (mean BMI = 21) and 21 boys (mean BMI = 19). Number of participants per snack condition and distribution of gender is shown in table 2.1.

Table 3.1: Number of participants and gender in each snack condition.

	Apple	**Banana**	**No Snack**
Girls	5	5	6
Boys	8	7	6
Total	13	12	12

Ethical approval was granted from Northumbria University School of Psychology and Sports Sciences Ethics Committee. Testing took place in a quiet area in the participating schools after consent had been granted from the head teachers. Informed consent was obtained from parents or guardians of all the participating children and further verbal consent was obtained from the children themselves. The children were instructed to consume their habitual breakfast on the day of testing and asked to write down everything they had consumed that morning before testing commenced. To calculate nutrient values of the breakfasts for further analysis, the breakfast records were later entered into DietMaster (see results section for further details). The children were given stickers for taking part and the participating schools were given a £10 Waterstones voucher as a token of appreciation.

3.2.3. Cognitive Test Battery

The CAMBA (Children's Attention and Memory) battery described in Chapter 2 was used in the current chapter. The test battery consists of five computerised attention and memory tests presented in the following order: Simple Reaction Time, Choice Reaction Time, Corsi Blocks, Continuous Attention Task, Odd-one-Out.

The battery takes approximately 15 minutes to complete with parallel forms presented at each test session.

3.2.4. Treatments

Children were randomly assigned to the apple, banana or no snack conditions. Approximately five minutes was allowed for snack consumption. Nutritional characteristics of each treatment condition are given in chapter 2 in Table 2.2.

3.2.5. Procedure

Participating children attended one test day only and were tested in groups of twelve maximum in a quiet area of their school. The children were instructed to consume their habitual breakfast on the test day. Upon arrival on the test day the children were randomly allocated to a treatment group (apple, banana or no snack) and asked to write down everything they had consumed (food and drink) that morning up until that point. The children were instructed that they were not allowed to consume anything but water until testing was finished that day. A practice session was run at 9.00 am. These data were not included in the analysis. As in chapter 2, one training session was deemed sufficient for the children to become familiar with the test battery and to avoid further disruption to class routine. Baseline (pre-snack) measures were taken at 9.45am. The snack was given at 10.00am and the children were tested again at 10.30am and 11.00am at 30 and 60 minutes post-snack, respectively. The inclusion of a test session at 90 minutes post-snack would have allowed for comparison with chapter 2. However, it was deemed unnecessary to include this session as it would interrupt classroom routine and chapter 3 is more of an extension to chapter 2 to see if earlier test sessions (30 and 60 min) would be more appropriate to detect effects of snack consumption.

An assumption was made that breakfast was consumed at approximately 8.00am. Thus it was estimated that cognitive testing took place 2½ and 3 hours following breakfast consumption which is broadly in line with the timings used by Muthayya et al. (2007) (2½ hrs) and Benton and Jarvis (2007) (3hrs 15 min).

3.2.6. Statistics

All data were analysed using SPSS.

For each outcome measure a one-way ANOVA was carried out on the baseline scores to test for differences between snack conditions.

Instead of using breakfast as a factor which is split into separate breakfast groups depending on calorific size, it was deemed more appropriate to enter calories consumed at breakfast as a covariate in the primary analysis of snack by assessment time (described in the next paragraph). If breakfast was to be split into the same groups as in chapter 2 (small and large) plus an additional no breakfast group as there were some participants who had not consumed breakfast, the cell occupancies would have been very low (e.g. 1 participant for no breakfast – banana or 3 participants in large breakfast – no snack). Hence, to remove the possible influence on cognitive performance scores, calorie intake at breakfast was included as a covariate.

Post-snack scores were analysed by a two-way ANCOVA [assessment time (30 and 60 min post-snack) x snack (apple, banana and no snack)]. Assessment time was a within-subjects variable and snack was a between-subjects variable. The covariate was the estimated amount of calories consumed at breakfast. If significant differences were found in cognitive performance at baseline, the baseline scores were entered as a further covariate in the analysis of the post-snack scores.

Where appropriate, post hoc pairwise comparisons were provided with a Bonferroni correction where there were significant differences ($p<0.05$). If analysis revealed significant interactions further one-way ANOVAs were carried out to clarify the interactions.

3.3. Results

Mean scores for each snack condition by assessment time are presented in Table 3.2.

3.3.1. Baseline Scores

Pre-snack baseline scores for each outcome measure were subjected to one-way ANOVAs prior to the primary analysis of the post-snack scores. There were no significant baseline differences on any of the measures.

Table 3.2: Mean scores (SD) on each measure across Snack conditions at pre-snack (baseline) and 30 and 60 minutes post-snack. Significant effects and trends are indicated in the last column (Ti = Time (assessment time), **p<0.05).

Measure	Condition	n	Pre-Snack	Post-snack		Significant effects & Trends
				30 minutes	60 minutes	
Simple RT (msec)	Apple	13	376.64 (10.42)	406.91 (72.24)	441.85 (70.02)	-
	Banana	12	352.10 (10.85)	380.56 (81.13)	455.46 (154.34)	
	No Snack	12	371.50 (10.85	408.69 (79.40)	442.67 (110.62)	
Choice RT (% correct)	Apple	13	96.92 (2.53)	92.50 (10.70)	93.46 (5.45)	-
	Banana	12	93.54 (5.16)	91.67 (5.04)	95.21 (3.91)	
	No Snack	12	94.38 (3.56)	94.16 (6.51)	93.96 (3.10)	
Choice RT (msec for correct responses)	Apple	13	578.71 (59.27)	620.20 (106.43)	649.26 (135.35)	-
	Banana	12	532.79 (65.79)	607.32 (175.66)	602.76 (124.46)	
	No Snack	12	550.49 (86.64)	595.13 (117.23)	632.66 (101.11)	
Corsi Blocks (no. correct)	Apple	13	17.62 (3.75)	18.00 (3.11)	17.00 (4.00)	-
	Banana	12	18.75 (3.67)	17.75 (2.86)	17.17 (2.89)	
	No Snack	12	16.17 (2.04)	18.08 (2.78)	15.67 (3..03)	
Continuous Attention (RT msec)	Apple	13	360.57 (75.85)	352. 31 (61.81)	334.52 (63.53)	-
	Banana	12	351.29 (45.40)	346.85 (45.46)	346.29 (59.08)	
	No Snack	12	356.75 (33.26)	350.96 (49.95)	338.57 (59.52)	
Continuous Attention (d')	Apple	13	3.50 (0.84)	3.51 (1.30)	3.47 (1.24)	-
	Banana	12	3.87 (1.10)	3.59 (1.01)	3.88 (1.15)	
	No Snack	12	3.93 (1.21)	3.35 (1.08)	3.25 (1.13)	
Odd-one-Out Recall (no. correct)	Apple	13	16.85 (4.00)	15.92 (4.46)	15.00 (5.89)	Ti**
	Banana	12	16.58 (4.10)	15.58 (2.35)	15.58 (2.47)	
	No Snack	12	15.42 (2.43)	15.50 (3.40)	15.42 (3.42)	

3.3.2. Simple Reaction Time

Analysis on the pre-snack scores showed no significant differences between the snack conditions ($F(2,34) = 1.46$; $p = 0.247$). Analysis on the post-snack scores revealed no significant main effect of snack ($F(2,33) = 0.061$; $p = 0.941$), assessment time ($F(1,33) = 0.512$; $p = 0.479$) or any significant interaction ($F(2,33) = 0.527$; $p = 0.595$).

3.3.3. Choice Reaction Time

3.3.3.1. Percentage correct responses

Pre-snack analysis showed no significant differences between the snack conditions ($F(2,34) = 2.61$; $p = 0.88$). Further analysis on the post-snack scores revealed no significant differences between the snack conditions ($F(2,33) = 0.163$; $p = 0.850$), assessment time ($F(1,33) = 0.571$; $p = 0.455$) or interaction ($F(2,33) = 0.904$; $p = 0.415$).

3.3.3.2. Reaction time for correct responses

Results showed no significant differences between the snack conditions on the pre-snack scores ($F(2,34) = 1.33$; $p = 0.278$). Further analysis on the post-snack scores revealed no significant effect of snack ($F(2,33) = 0.265$; $p = 0.768$), assessment time ($F(1,33) = 1.726$; $p = 0.198$) or interaction ($F(2,33) = 0.359$; $p = 0.701$).

3.3.4. Corsi Blocks

There were no significant differences between the snack conditions on the pre-snack scores ($F(2,34) = 1.89$; $p = 0.167$). Analysis on the post-snack scores showed no significant effect of snack ($F(2,33) = 0.209$; $p = 0.813$), assessment time ($F(1,33) = 0.328$; $p = 0.571$) or interaction ($F(2,33) = 0.997$; $p = 0.380$).

3.3.5. Continuous Attention Task

3.3.5.1. Reaction Time

There were no significant differences between the snack conditions on the pre-snack scores ($F(2,34) = 0.089$; $p = 0.915$). Results on the post-snack scores showed no significant effects of snack ($F(2,33) = 0.015$; $p = 0.985$), assessment time ($F(1,33) = 0.760$; $p = 0.390$) or interaction ($F(2,33) = 0.338$; $p = 0.716$).

3.3.5.2. d'

Analysis revealed no significant differences between the snack conditions on the pre-snack scores ($F(2,34) = 0.64$; $p = 0.534$). Results on the post-snack scores showed no significant effects of snack ($F(2,33) = 0.506$; $p = 0.607$), assessment time ($F(1,33) = 1.321$; $p = 0.259$) or interaction ($F(2,33) = 0.318$; $p = 0.730$).

3.3.6. Odd-one-Out

Results showed no significant differences between the snack conditions on the pre-snack scores ($F(2,34) = 0.55$; $p = 0.584$). Analysis on the post-snack scores revealed no significant effect of snack ($F(2,33) = 0.008$; $p = 0.992$) or interaction ($F(2,33) = 0.268$; $p = 0.767$). There was, however, a significant effect of assessment time ($F(1,33) = 6.009$; $p = 0.020$) with better performance at 30 minutes (15.67) than at 60 minutes (15.33) post-snack (Fig. 3.1).

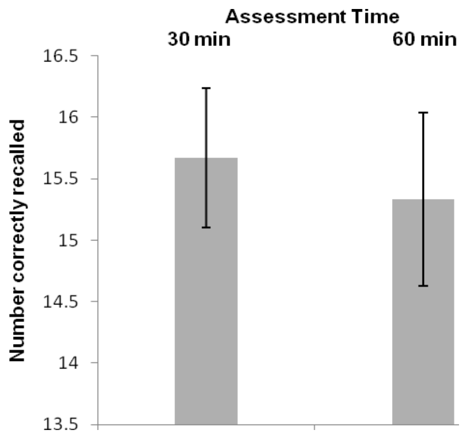


Figure. 3.1: Main effect of assessment time on the odd-one-out test.

3.4. Discussion

The current experiment was carried out as an extension of the experiment in Chapter 2 to examine whether the effects of a mid-morning snack could be detected 30 and 60 minutes rather than 90 minutes post-snack. Consistent with the results in Chapter 2, the current experiment did not find any effects of a mid-morning snack on children's attention and memory. It should be noted, however, that although the experiments in chapters 2 and 3 both set out to investigate whether children's attention and memory can be affected by the consumption of a mid-morning snack chapter 2 included breakfast (kcal) as an independent variable whereas in chapter 3 breakfast was included as a covariate because the cell occupancy would be very small if divided into breakfast groups. It also has to be noted that although it was recognised earlier in this chapter that the time of breakfast consumption prior to testing was not recorded in chapter 2, it was decided not to do so in the current study either as it would involve the children having to recall when they had consumed their breakfast or alternatively provide them with diaries which could have deterred some children from taking part. Instead, an assumption was made that breakfast was consumed at approximately 8.00am. In the current chapter there was a significant main effect of assessment time on the odd-one-out task, with better performance at 30 minutes post-snack than at 60 minutes post-snack. These results partially support previous findings that cognitive performance declines throughout the morning (e.g. Wesnes et al., 2003).

Overall, the results showed no significant effect of snack, suggesting that children's attention and memory is not affected by the consumption of a mid-morning snack. The present findings seem to contradict previous findings (Busch et al., 2002; Benton & Jarvis, 2007; Muthayya et al., 2007) that suggest that snack consumption can be beneficial to children's performance. However, although previous studies have found significant effects of snack there are a number of measures in these studies that did not reach statistical significance. Busch et al. (2002), for example, found that snack consumption has an effect on sustained attention but not on memory. On the contrary, Muthayya et al. (2007) found an effect on memory but not sustained attention. Benton and Jarvis (2007) found an effect on attention as measured by how much time children spent concentrating on a task. It should be noted, however, that the effects of snack in the latter two studies were only observed if prior breakfast intake was taken into account and, additionally, Muthayya et al. only found effects in their low SES sample.

It is also important to note that the in the current study the snacks were different from the snacks provided by Busch (2002), Benton and Jarvis (2007) and Muthayya et al. (2007). The snacks in the current study, apple and banana, were chosen in order for them to be comparable with what children would normally be provided with in school as a mid-morning snack so it would be easier to generalise the results to children's everyday lives. By doing this however, the snacks differed from snacks used in previous research. Furthermore, the snacks used in the current study also differed from each other in terms of calories, macronutrients and in taste, which could have potential confounding effects on the results. There is also the possibility that an association effect might occur where participants' familiarity with the snacks might influence the results.

Contrary to previous research suggesting that raised blood sugar levels induced by CHO intake can have positive effects on cognitive performance (e.g. Benton et al., 2003; Benton & Sagent, 1992; Kanarek & Swinney, 1990; Markus et al., 1998; Markus, Panhuysen, Jonkman, & Bachman, 1999) the current study (and the study in chapter 2) did not find any benefits of carbohydrate-induced rise in blood glucose via snack intake on children's cognitive performance. It is possible that the carbohydrate intake associated with the consumption of apples and bananas is too low (See table 2.2) to sufficiently raise blood sugar levels to detect any effects on cognitive performance when compared to snack omission. The carbohydrate content of apple was 11.50g (per 100g) and of banana it was 23.2g (per 100g) with a higher ratio of fructose-to-glucose for apple.

An alternative explanation for the lack of significant effects of snack is that it could be due to the low cognitive demand of the cognitive test battery. Previous studies have suggested that the facilitating effects of glucose can only be detected if the test battery is high in cognitive demand (e.g. Scholey et al., 2001). The tasks on the current test battery might not have had a high enough cognitive demand to allow for any variations in cognitive performance to be detected. Altering the tasks for future research could possibly affect the results in that a more demanding test battery might be more sensitive to the effects of snacks. However, given that one significant difference was found on assessment time (this chapter) and also that there was a trend towards a main effect of snack in chapter 2, it seems that the current test battery is capable of picking up some changes in performance and warrants further testing with the CAMBA battery.

The current study and the study in chapter 2 also set out to explore whether the GI of the snacks would play a role in the effects on cognitive performance. The results showed no significant effect of the GI of the snacks. This lack of significant results could be due to the fact that the GI values of apples and bananas are not that different and it might be interesting to use snacks or other food at more opposing ends of the GI scale to investigate the effects of GI on cognitive performance. The results from Vaisman et al.'s (1996) study showed that children who consumed breakfast in school performed better than children who had consumed breakfast at home or not consumed any breakfast. Although Vaisman et al. argued that this was due to the timing of the breakfast and the shorter delay between breakfast and cognitive test for children who had breakfast at school compared to home, Vaisman et al. did acknowledge that their results could be due to differences in breakfast content rather than timing. Through participant reports, the authors recognise that what the children were having for breakfast at home was nutritionally different from the cornflakes they were provided with in school and hence could have affected the results. Previous research has argued that breakfast consumption is beneficial for cognitive performance (Benton & Jarvis, 2007; Benton & Stevens, 2008; Mahoney et al., 2005; Muthayya et al., 2007; Vaisman, 1996; Wesnes et al., 2003; Widenhorn-Müller, 2008). However, it is not until recently that there has been an increased interest in investigating if there are any differential effects of foods with different nutritional content. If differences in food content have an influence on children's cognitive performance such findings will be crucial in the development of school curricula in order to put children in the optimal position for learning and achievement.

CHAPTER 4: The Effects of Glycaemic Index of Breakfast on Children's Cognitive Performance

4.1. Introduction

Numerous studies have found acute improvements in cognitive performance on a range of different tasks following the consumption of glucose in adults (e.g. Kennedy & Scholey, 2000). However, there is not much research on the effects of pure glucose in children. As discussed in the chapter 1, the little research that has been done in children (Benton, et al., 1987; Benton & Stevens, 2008, Wesnes et al., 2003) and adolescents (Smith et al., 2009; 2011) has found some positive effects on performance. Benton et al. (1987) found faster reaction times and better concentration following a glucose load and Benton and Jarvis (2008) found improved picture recall following glucose (both provided 25g glucose) although in the latter study there were no effects on spatial memory or on sustained attention. Furthermore, Wesnes et al. (2003) showed impairment in performance (memory and attention) following a glucose load. It is important to note, however, that Wesnes provided a much larger dose of glucose (38.7g) compared to the studies by Benton et al. (1987; 2008). It is also worth noting that the two studies by Benton et al. did not control for prior dietary intake (breakfast and lunch) which could have had potential confounding effects on the results.

If glucose does have an effect on cognitive performance, it is reasonable to argue that any intervention which alters blood glucose may also have an effect on performance. Hence, the consumption of drink and food should have an effect on cognitive performance. As the body's main source of glucose is via carbohydrates, it would be reasonable to assume that carbohydrate consumption can alter cognitive performance and that we might see differences in performance following intake of high and low GI food. Recent research has suggested that foods with a low GI are associated with better cognitive performance in children.

A study published in the USA directly investigated the effect of breakfasts of differing GIs on cognitive processes in children. In this study, Mahoney et al. (2005) examined the effects of GI in thirty children aged 6 to 11 years. Cognitive performance was assessed by completion of a battery of cognitive tests consisting of spatial memory, short-term memory, visual perception, visual attention, auditory attention, and verbal memory. Following an overnight fast the children consumed either a low GI breakfast (oatmeal), a high GI breakfast (ready-to-eat cereal) or they received no breakfast (GI values were not reported). All children took part in all breakfast conditions over a three week period. Breakfast was given at 8:15 to 8:30 a.m. and testing took part an hour later between 9:30am and 10:30a.m. Overall, the results suggest that breakfast enhances cognitive performance when compared to no breakfast. Furthermore, when comparing the high and low GI breakfasts, Mahoney et al. found that the younger children (aged 6-8 years) performed better on an auditory attention task and spatial memory task after the low GI breakfast (oatmeal) and that girls but not boys aged 9-11 years performed better on a short-term memory task after the consumption of the low GI breakfast compared to the high GI breakfast (cereal).

Wesnes et al (2003) investigated the effects of two cereals, Shreddies (38.5 g CHO / 25.2g complex CHO) and Cheerios (28.7g CHO / 16.0g complex CHO), glucose (38.3g) and no breakfast on memory and attention in 29 children aged 9-16 years. Over four consecutive days the children were assessed on a battery of tests from the Cognitive Drug Research (CDR) measuring attention, working memory and episodic secondary memory. Each child was given a different breakfast on each day. The tests were completed at 30, 90, 150 and 210 minutes following breakfast consumption. Wesnes et al. found that if children consumed a glucose drink or no breakfast, their attention and memory declined throughout the morning (8 a.m. to 12 p.m.). This decline, however, was prevented in the two breakfast conditions for power (speed) of attention and episodic memory. The observed decline in attention and episodic memory for children who had no breakfast or a glucose drink was reduced by more than half by having carbohydrates in the form of cereal for breakfast.

Wesnes et al.'s study shows that having breakfast in the form of cereal might be beneficial on some cognitive measures compared to performance after the consumption of a glucose drink or no breakfast. However, on closer inspection of the nutrient content of the two cereals it is clear that the cereals used in Wesnes et al.'s study do not contain an equal amount of carbohydrates (other macronutrient content is not reported). Although the results from this study are not very clear, the authors seem to report a significant main effect of treatment (i.e. cereal) but do not report any further detail as to whether there were any differences in performance between the two cereals. It appears that despite the differences in composition between the two cereals there were no differences in cognitive performance between them.

The current chapter set out to investigate the effects of GI of breakfast on children's cognitive performance. This was achieved by comparing the effects of a high GI cereal, a low GI cereal and breakfast omission (no breakfast) on attention and memory in children aged 8 to 10 years. The cognitive test battery assessing attention and memory (CAMBA) was completed immediately following breakfast consumption and again at 60 and 120 minutes post-breakfast. To establish what type of cereal to use as the high and low GI cereals, a pilot study was carried out to examine what children usually consume for breakfast in the North East of England where testing took place.

Based on previous literature, the main hypothesis was that performance following the consumption of the low GI cereal would be better than after the consumption of the high GI cereal or breakfast omission. Furthermore, based on previous literature suggesting that there is a decline in children's cognitive performance from early to late morning (e.g. Muthayya et al., 2007; Wesnes et al., 2003), it was predicted that the current results would show a decline in children's performance throughout the morning.

4.2. Pilot Study: Breakfast Survey

4.2.1. Rationale

In a review in 2005, Rampersaud et al. reported that children in a number of countries most commonly consumed milk for breakfast. They also stated that bread and breakfast cereals are also commonly consumed by children and that this tendency was similar across a number of countries. The authors also reported that breakfast omission is common in both the United States (10%) and in the UK (30%). More recently, Kellogg's (Kellogg's Press Office, 2009) published a report on breakfast habits in children aged 7 to 14 years (in the UK). The report revealed that 24% of the children who took part in the study frequently have chocolates, sweets, cakes and biscuits for breakfast. They also found that 160,000 children have crisps for breakfast and that more than 100,000 have carbonated drinks. Access to the report, however, is not readily available and any information on the total sample size or sampling method for this survey has not been found and hence it is difficult to make conclusions about the exact meaning of these numbers and also difficult to say that the sample is representative.

In order to investigate the effect of the glycaemic index of breakfast on children's cognitive performance in the current chapter it was imperative to obtain recent data regarding children's typical breakfast eating habits in the area where the research was to be carried out. Hence, a survey of what children consume for breakfast was carried out in order to get an idea of what children aged 7 to 11 years generally have for breakfast. Based on the information provided from this survey it can be determined what particular types of breakfast to employ as treatments in the main study investigating the effects of GI of breakfast on children's cognitive performance.

4.3. Method

4.3.1. Participants

Parents of 125 children aged 7 to 11 years (mean age 9:2, range 7:1 – 11:1) took part in the survey. Participants were recruited through schools in and around Newcastle and County Durham and were from a range of socio-economic backgrounds. Ethical approval was granted from Northumbria University School of Psychology and Sports Sciences Ethics Committee.

4.3.2. Measures

A breakfast survey questionnaire (Appendix 5) was designed asking parents what their children generally eat and drink for breakfast. The questions were open ended and encouraged parents to write down everything their children would normally eat and drink, including chocolates and crisps. Parents were also asked to be as specific as possible.

4.3.3. Procedure

Ten schools were approached and asked to take part in the survey. Three of the schools agreed and the questionnaires were sent out to these 3 schools. The questionnaires were distributed to parents and returned to the schools via the pupils. The head teacher of the participating school consented to the study taking place in the school prior to its commencement. Informed consent was also obtained from parents.

4.4. Results

Questionnaires for 125 children were returned. Table 4.1 shows the percentage of the children who consumed the different types of foods and drink. The table also contains information about when and where the children consumed breakfast. However, this information was exploratory in nature and was not directly connected to the current study.

The results show that the top five cereals habitually consumed by the 125 children were: Weetabix (30.4%), Coco Pops (20%), Corn Flakes (18.4%), Cheerios (17.6%) and Rice Krispies (13.6%). Only one child habitually had no breakfast although a few of the children occasionally skipped breakfast.

Table 4.1: Number and percentage of 125 children who habitually consumes the following food and drink items. One child can have more than one entry (e.g. can have one entry for Weetabix and one for apple). The table also contains information about when and where the children usually eat breakfast.

	n	**%**
Weetabix	38	30.4
Coco Pops	25	20
Corn Flakes	23	18.4
Cheerios	22	17.6
Rice Krispies	17	13.6
Shreddies	17	13.6
Frosties	14	11.2
Sugar Puffs	13	10.4
Weetos	12	9.6
Cereal (not specified)	9	7.2
Ready Brek	9	7.2
Crunchy Nut Corn Flakes	5	4
Golden Nuggets	4	3.2
Bran Flakes	3	2.4
Cookie Crisp Cereal	3	2.4
Nesquick Cereal	3	2.4
Chocolate Loops	2	1.6
Frosted Wheats	2	1.6
Fruit & Fibre	2	1.6

	n	**%**
Toast (not specified)	31	24.8
White toast	36	28.8
Brown toast	15	12
Milk Roll	1	0.8
Crumpets	8	6.4
Pancakes	4	3.2
Potato Waffles	1	0.8
Croissant	1	0.8
Muffin	1	0.8
Fairy Bun	1	0.8
Jam	7	5.6
Butter	6	4.8
Peanut butter	5	4.0
Flora	4	3.2
Cheese	3	2.4
Marmite	3	2.4
Chocolate Spread	2	1.6

	n	**%**
Fruit (not specified)		8.0
Banana		5.6
Apple		3.2
Pear		3.2
Peach		1.6
Egg hard boiled		6.4
Bacon Sandwich		2.4
Beans		2.4
Egg scrambled		0.8
Cereal Bar		2.4
Frosties Cereal Bar		0.8
Rice Krispies Cereal Bar		0.8
Biscuits		4.0
Chocolate Biscuits		4.0
Crackers		0.8

Honey Nut Shreddies	2	1.6
Shredded Wheat	2	1.6
Chocolate Scooby-Doos	1	0.8
Chocolate Squares	1	0.8
Cinnamon Grahams	1	0.8
Golden Balls	1	0.8
Honey Loops	1	0.8
Honey Nut Shredded Wheat	1	0.8
Honey Balls	1	0.8
Sultana Bran	1	0.8
Porridge	8	6.4
Oat-so-simple	2	1.6
Scottish Oats	2	1.6
Ready Oats	1	0.8
Oatmeal	1	0.8
Yoghurt (not specified)	6	4.8
Fromage Frais	1	0.8
Nothing to eat	1	0.8
Sometimes skips	13	10.4

Marmalade	1	0.8
Treacle	1	0.8
Honey	1	0.8
Tea	32	25.6
Coffee	4	3.2
Hot Chocolate	3	2.4
Juice (not specified)	44	35.2
Orange Juice	30	24
Apple Juice	3	2.4
Cranberry Juice	2	1.6
Blackcurrant	6	4.8
Pop	6	4.8
Squash	3	2.4
Milk	41	32.8
Water	12	9.6

Crisps	3	2.4
Kit Kat	1	0.8
Twix	1	0.8
Chocolate	1	0.8
Jaffa cakes	1	0.8
Chocolate raisins	1	0.8
Breakfast consumed before 6.00	0	0
Breakfast consumed 6.00-6.30	0	0
Breakfast consumed 6.30-7.00	2	1.6
Breakfast consumed 7.00-7.30	14	11.2
Breakfast consumed 7.30-8.00	68	54.4
Breakfast consumed 8.00-8.30	39	31.2
Breakfast consumed 8.30-9.00	1	0.8
Breakfast consumed after 9.00	0	0
Breakfast consumed at:		
Kitchen/dining table/bar	78	62.4
In front of TV	38	30.4
In living room	13	10.4
In bed	2	1.6
In bedroom	1	0.8

4.5. Discussion

The data obtained from the breakfast survey show that most of the participating children had cereal or toast for breakfast. More children have white than brown toast and the most popular cereals, with the most popular first, are: Weetabix, Coco Pops, Corn Flakes, Cheerios and Rice Krispies. Some of the children had crumpets, biscuits, porridge and fruit (in particular apple and banana). Only one child habitually had no breakfast although a few of the children occasionally skipped breakfast. Only a few children had bacon, beans, chocolate or crackers for breakfast.

Based on the results of the Breakfast Survey, *Coco Pops* was considered to be the most appropriate choice of high GI cereal for the current study as it was the second most popular cereal amongst children in the survey. However, selecting the low GI cereal was more difficult as such a cereal was not present amongst the choices in the survey. The low GI cereal, *All Bran*, was therefore chosen based on the values from an international table of glycaemic index (Foster-Powell et al., 2002). All Bran was chosen as it has one of the lowest GIs for cereals and because it is readily available in the shops in the areas where testing would ultimately take place.

4.6. Main Study: Effects of GI of Breakfast on Attention and Memory

The current main study set out to investigate the effects of the glycaemic index of two breakfast cereals, Coco Pops (high GI) and All Bran (low GI) on children's cognitive function.

4.7. Method

4.7.1. Design

The design used in the current study was a mixed measures design (Breakfast x Assessment Time) with two independent variables. Breakfast was a between subjects variable with three levels: High GI (Coco Pops), Low GI (All Bran) and No Breakfast. Assessment Time was a within subjects variable with three levels: 9.40am, 10.40am and 11.40am. As the participating children would be out of class for most of the morning, it was decided to have the breakfast variable as a between subjects variable so they only had to miss classes on one day rather than three. The post-dose test times were chosen to keep time intervals similar to those of Wesnes et al. (2003) who tested at approximately hourly intervals and to Mahoney et al. (2005) who tested one hour after breakfast. The dependent variable was the scores on the cognitive tests.

4.7.2. Participants

Thirty-eight children aged 8 to 10 years (mean age: 9 years 5 months, age range: 8 years 6 months – 10 years 7 months) were recruited from a school in the North East of England encompassing children from middle to high socio-economic backgrounds. Ethics approval was granted by the Northumbria University School of Psychology and Sports Sciences Ethics Committee. There were 19 girls (mean BMI = 16) and 19 boys (mean BMI = 16). The age group in the current study was chosen in order to test children of a younger age around the time when they reach adult levels of glucose metabolism (9 years: Johnson, 2003; 9-10 years: Chugani, 1987; 1994) as it is possible that these younger children are more sensitive to nutritional manipulations.

Table 4.2: Number of participants and gender in each breakfast condition.

	All Bran	**Coco Pops**	**No Breakfast**
Girls	6	8	5
Boys	7	6	6
Total	13	14	11

Prior to commencement of the study, the participating head teacher consented to the study taking place in the school. The parents/guardians of the participating children also gave consent to their child(ren) taking part and verbal consent was given from each participating child on the day of testing. All children were instructed to fast from 10pm the night prior to the study. The children were given stickers for taking part and the schools were given a £10 Waterstones voucher as a token of appreciation.

4.7.3. Cognitive Test Battery

The cognitive test battery was identical to the test battery in chapters 2 and 3 and was the CAMBA (Children's Attention and Memory) battery which consisted of: Simple Reaction Time, Choice Reaction Time, Corsi Blocks, Continuous Attention Task and Odd-one-Out.

4.7.4. Treatments

Based on the outcome of the Pilot study (Breakfast Survey), Coco Pops was selected as the high GI cereal and All Bran was selected from an international table of glycaemic index (Foster-Powell et al., 2002) as the low GI cereal.

On the day of testing children were randomly assigned to one of three breakfast conditions: Coco Pops, All Bran or No Breakfast. Both cereals were accompanied by 125ml semi-skimmed milk. Nutritional characteristics of each treatment condition are given in Table 4.3. Although the composition of the two breakfasts were different, these breakfasts were matched in weight rather than e.g. calorie content so that the breakfasts would be close to what a portion size would normally be like and similar to children's habitual breakfasts to allow the findings to be applied to an everyday setting. Approximately ten minutes was allowed for breakfast consumption.

Table 4.3: Nutritional characteristics of 35g of All Bran and 35g Coco Pops. The GI value is taken from an international table of glycaemic index (Foster Powell et al., 2002).

Nutrient	Units	All Bran	Coco Pops	No Breakfast
Energy	kcal	98	133	
Protein	g	4.9	1.6	n/a
Fat	g	1.6	0.9	All values=0
Fibre	g	9.5	0.7	
Carbohydrate	g	16.1	29.8	
Sugars	g	2.45	11.9	
Starch	g	10.85	17.85	
Glycaemic Index	GI	42	77	

4.7.5. Procedure

Each child was required to attend only one active study day. The children were tested in groups of a maximum of twelve in a quiet area of their school. On arrival on the test day the children were randomly allocated to a treatment group and the experimenter ran through the test battery with the children to familiarise them with the procedure. These data were not included in any analyses. Prior to testing the children had been instructed not to consume any food or drink (other than water) from 10pm the night before testing. On the test day they were instructed that they were not allowed to consume anything but water until testing was finished that day.

Baseline measures were taken at 9.00am after an overnight fast. Breakfast was given at 9.30am and the children were tested again at 9.40am, 10.40am and 11.40am. Each test session lasted approximately 15 minutes.

4.7.6. Statistics

All data was analysed using SPSS.

For each cognitive measure, change from baseline scores were analysed by a two-way mixed ANOVA [assessment time (9.40am, 10.40am and 11.40am) x breakfast (All Bran, Coco Pops and No Breakfast)]. Assessment time was a within subjects variable and breakfast was a between subjects variable.

Where appropriate, post hoc pairwise comparisons (Bonferroni corrected) were provided where there were significant differences ($p<0.05$). If analysis revealed significant interactions further one-way ANOVAs were carried out to elucidate the interactions.

There is some debate as to whether it is better to analyse pre-test – post-test data by ANCOVA on the raw data with the pre-test (baseline) scores as the covariate rather than analyse it by ANOVA on change from baseline scores (e.g. Dimitrov & Rumrill, 2003). Hence, alternative analysis by ANCOVA was carried out and the results are presented in Appendix 10. As can be seen in Appendix 10, this analysis did not alter the results a great deal.

4.8. Results

Mean scores on baseline and each assessment time are presented in Table 4.4 and mean change from baseline scores for each condition at each assessment time are presented in Table 4.5. For plots of raw data for each measure and a list of all F-values see appendices 8 and 9 respectively.

4.8.1. Simple Reaction Time

There were no significant main effects of Assessment Time ($F(2,70) = 0.413$; $p = 0.663$) or Breakfast ($F(2,35) = 5.110$; $p = 0.594$) or any significant interaction ($F(4,35) = 0.742$; $p = 0.567$).

Table 4.4: Mean scores (SD) on baseline and at each assessment time for each breakfast condition.

Measure	Condition	Baseline	9.40 am	10.40 am	11.40 am
Simple RT (msec)	Coco Pops	414.37 (56.51)	419.65 (67.00)	470.50 (137.80)	439.80 (62.91)
	All Bran	392.21 (52.86)	402.04 (67.51)	400.27 (69.35)	402.80 (62.91)
	No Break	472.80 (88.40)	507.70 (186.09)	501.32 (94.63)	520.35 (129.30)
	Total	423.70 (72.38)	443.13 (18.67)	457.37 (17.30)	454.31 (14.28)
Choice RT (msec for correct responses)	Coco Pops	674.79 (91.49)	688.04 (139.31)	680.58 (134.89)	683.63 (102.66)
	All Bran	627.98 (73.67)	621.54 (84.81)	637.27(81.52)	615.97 (74.72)
	No Break	786.14 (213.98)	814.33 (220.11)	763.62 (126.65)	700.70 (121.69)
	Total	691.01 (145.81)	707.97 (25.00)	693.82(19.03)	666.77 (16.35)
Corsi Blocks (no. correct)	Coco Pops	15.36 (3.99)	13.86 (4.92)	14.86 (3.74)	13.57 (4.30)
	All Bran	13.69 (4.87)	14.54 (4.37)	14.23 (5.24)	14.31 (4.55)
	No Break	14.18 (2.18)	15.09(1.81)	13.73 (2.80)	13.55 (3.45)
	Total	14.45 (3.89)	14.50 (0.66)	14.27 (0.67)	13.81 (0.68)
Continuous Attention (RT msec))	Coco Pops	284.62 (135.24)	296.66 (101.82)	295.81 (113.31)	279.37 (100.90)
	All Bran	371.36 (56.43)	361.86 (44.78)	372.10 (55.96)	376.25 (40.47)
	No Break	323.87 (116.65)	323.24 (80.26)	336.61 (51.67)	348.08 (57.96)
	Total	325.66 (111.84)	327.25 (13.02)	334.84 (13.25)	334.56 (11.87)
Continuous Attention (d')	Coco Pops	0.55 (0.53)	0.76 (0.17)	0.76 (0.19)	0.74 (0.23)
	All Bran	0.65 (0.19)	0.69 (0.19)	0.72 (0.15)	0.71 (0.16)
	No Break	0.44 (0.51)	0.67 (0.16)	0.57 (0.29)	0.60 (0.27)
	Total	0.56 (0.43)	0.71 (0.03)	0.69 (0.04)	0.68 (0.404)
Odd-one-Out Recall (no. correct)	Coco Pops	12.71 (3.52)	13.00 (6.08)	13.93 (4.38)	13.14 (4.07)
	All Bran	14.15 (3.63)	14.85 (4.08)	14.77 (4.15)	14.15 (3.72)
	No Break	11.27 (3.13)	10.91 (2.81)	13.09 (4.01)	11.82 (4.02)
	Total	12.79 (3.55)	12.92 (0.76)	13.93 (0.68)	13.04 (0.64)

Table 4.5: Mean change from baseline scores (SD) for each condition across post-breakfast assessment time. Significant effects are indicated in the last column (Ti = Time (assessment time), Bf = breakfast, *p<0.05).

Measure	Condition	n	Change from baseline				Significant effects
			9.40 am	10.40 am	11.40 am	Total	
Simple RT (msec)	Coco Pops	14	5.28 (51.42)	56. 13 (114.98)	25.43 (56.59)	28.95 (18.23)	-
	All Bran	13	9.83 (46.66)	8.07 (52.64)	10.59 (45.81)	9.50 (18.92)	
	No Break	11	34.90 (187.09)	28.52 (76.09)	47.54 (102.98)	36.99 (20.57)	
	Total		16.67 (17.66)	30.90 (14.13)	27.85 (11.46)		
Choice RT (msec for correct responses)	Coco Pops	14	13.25 (101.80)	5.79 (109.72)	8.84 (82.23)	9.29 (21.96)	
	All Bran	13	-6.44 (76.24)	9.28 (51.53)	-12.52 (61.16)	-3.06 (22.79)	Ti*
	No Break	11	28.19 (82.42)	-22.52 (154.69)	-85.44 (156.00)	-26.59 (24.77)	Bf x Ti*
	Total		11.67 (13.62)	-2.48 (18.02)	-29.54 (16.90)		
Corsi Blocks (no. correct)	Coco Pops	14	-1.50 (2.88)	-0.50 (1.74)	-1.79 (1.72)	-1.26 (0.87)	-
	All Bran	13	0.85 (5.37)	0.54 (5.55)	0.62 (5.12)	0.67 (0.91)	
	No Break	11	0.91 (1.51)	-0.45 (2.73)	-0.64 (2.66)	-0.06 (0.98)	
	Total		0.09 (0.60)	-0.14 (0.61)	-0.60 (0.57)		
Continuous Attention (RT msec)	Coco Pops	14	12.04 (98.21)	11.18 (118.15)	-5.26 (119.77)	5.99 (23.09)	-
	All Bran	13	-9.50 (45.28)	0.74 (56.97)	4.88 (39.95)	-1.29 (23.97)	
	No Break	11	-0.63 (84.41)	12.74 (124.25)	24.21 (80.64)	12.11 (26.05)	
	Total		1.00 (77.88)	8.06 (100.79)	6.74 (86.38)		
Continuous Attention (d')	Coco Pops	14	0.21 (0.45)	0.21 (0.48)	0.19 (0.46)	0.20 (0.10)	-
	All Bran	13	0.04 (0.16)	0.07 (0.13)	0.05 (0.19)	0.53 (0.10)	
	No Break	11	0.23 (0.43)	0.13 (0.48)	0.16 (0.41)	0.17 (0.11)	
	Total		0.16 (0.06)	0.14 (0.06)	0.13 (0.06)		
Odd-one-Out Recall (no. correct)	Coco Pops	14	0.29 (5.04)	1.21 (2.42)	0.43 (2.90)	0.64 (90.76)	-
	All Bran	13	0.69 (3.64)	0.62 (3.88)	0.00 (3.32)	0.44 (0.79)	
	No Break	11	-0.36 (2.38)	1.82 (2.96)	0.55 (3.05)	0.67 (0.86)	
	Total		-1.01 (0.59)	1.01 (0.59)	0.12 (0.58)		

4.8.2. Choice Reaction Time

4.8.2.1. Percentage correct responses

An error occurred in the recording of the percentage correct responses and hence no results are presented for this measure.

4.8.2.2. Reaction time for correct responses

Analysis revealed a significant main effect of Assessment Time ($F(2,70) = 3.404$; $p=0.039$). Pairwise comparisons did not show any significant differences between any of the time points (Fig. 4.1).

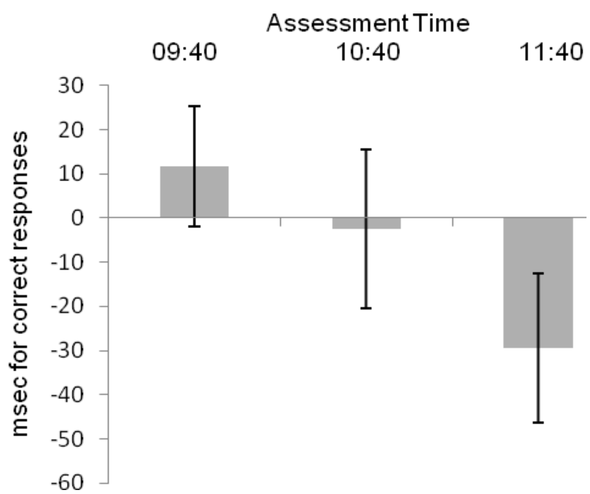


Figure. 4.1: Main effect of assessment time on reaction time scores for the choice reaction time test.

There was no significant main effect of Breakfast (*F*(2,35) =0.595; *p*=0.557). There was, however, a significant interaction between Assessment Time and Breakfast (*F*(4,70) = 2.513; *p*=0.049). Further one-way ANOVAs on breakfast for each test time revealed no significant main effect of breakfast at 9.40am (*F*(2,35) = 0.522; *p=0.598*), 10.40am (*F*(2,35) = 0.291; *p=0.749*) or at 11.40am (*F*(2,35) = 2.717; *p=0.080*). To further elucidate the interaction effect one-way ANOVAs were carried out to examine any differences between time points for each breakfast condition. The analysis revealed no significant effects for Coco Pops (F(2,26) = 0.092; p = 0.913), All Bran (F(2,24) = 0.852; p = 0.437) or No Breakfast (F(2,20) = 2.984; p = 0.073). Due to the lack of data for accuracy performance, speed-accuracy trade-off in the reaction time results cannot be ruled out.

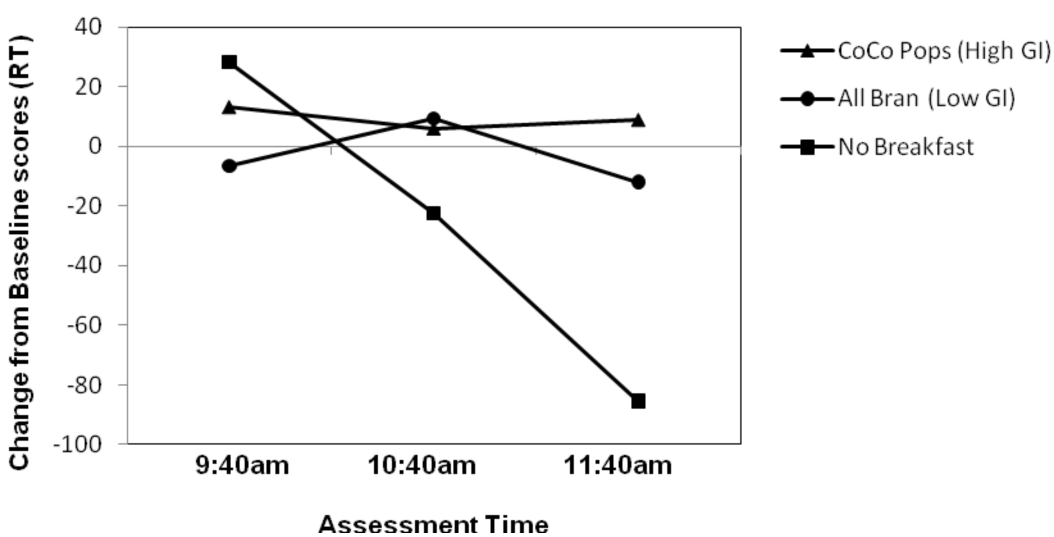


Figure. 4.2: Reaction time scores on Choice Reaction Time for each Breakfast condition by Assessment Time.

4.8.3. Corsi Blocks

Analysis showed no significant main effect of Assessment Time ($F(2,70) = 1.219$; $p=0.302$) or Breakfast ($F(2,35) = 1.205$; $p=0.312$) or any significant interaction effect ($F(4,70) = 1.363$; $p=0.256$).

4.8.4. Continuous Attention Task

4.8.4.1. Reaction time for correct responses

There were no significant effects of breakfast ($F(2,35) = 0.072$; $p = 0.930$), assessment time ($F(2,70) = 0.589$; $p = 0.558$) or interaction ($F(4,70) = 1.357$; $p = 0.258$).

4.8.4.2. d'

Analysis revealed no significant main effects of Assessment Time ($F(2,70) = 0.308$; $p=0.736$) or Breakfast ($F(2,35) = 0.623$; $p=0.542$) or significant interaction ($F(4,70) = 0.626$; $p=0.646$).

4.8.5. Odd-one-Out

The results showed no significant main effects of Assessment Time ($F(2,70) = 2.114$; $p=0.128$) or Breakfast ($F(2,35) = 1.582$; $p=0.217$) or significant interaction ($F(4,70) = 0.744$; $p=0.565$).

4.9. Discussion

The first part of the current study was to examine children's breakfast habits in Newcastle and County Durham areas (an area of the UK where the main part of the study was to be carried out). In contrast to previous surveys which have reported that a high number of children habitually skip breakfast (e.g. Kellogg's, 2009) the breakfast survey in the current study only found that one child habitually skipped breakfast, although a few of the children occasionally missed breakfast. Furthermore, in contrast to the report by Kellogg's (2009), the current study found that few children consumed unhealthy foods such as chocolate and crisps for breakfast. These results are encouraging given the high number of children who reportedly skip breakfast (e.g. Rampersaud et al., 2005). However, it has to be acknowledged that there is a possibility that the results might be confounded by desirability effects as parents may not have answered honestly on the questionnaire in the current survey. An alternative interpretation is that the current results could be down to location of the participating schools and the schools' catchment areas. Rampersaud et al. (2005) reported that breakfast omission was dependent on population. It is possible that parents/children from lower SES areas did not return the questionnaire and hence the sample represents middle to high SES children. This could possibly explain why hardly any children skipped breakfast or consumed unhealthy foods for breakfast. On the other hand, consistent with Rampersaud et al.'s review the current survey found that a large proportion of the children have cereal and bread for breakfast. Further supporting previous research (as reported by Rampersaud et al.), the current results show that a high proportion of the children have milk for breakfast as well as revealing that many have juice and tea for breakfast as well.

Kellogg's (2009) reported that parents under the age of 24 years were more likely to give their children money for breakfast instead of giving them breakfast at home and that two thirds of the children who were given breakfast money said that they spent it on unhealthy food. The current breakfast survey did not specifically ask if parents provided their children with money for breakfast or whether the children consumed breakfast outside of their home. Such statistics are therefore not available and it is likely that the results reflect what children consume at home before leaving the house. Furthermore, the sample used in the current survey is relatively small and focussed in one area of the UK. However, the purpose of the survey was not to conduct a national survey on children's breakfast habits but to concentrate on a particular geographical area in order to identify what types of breakfast are consumed most in this area to determine which cereals would be most appropriate to employ as breakfast manipulations in the main study.

The main study investigated the effects of breakfast consumption versus no breakfast consumption as well as investigating the effects of a high GI cereal versus a low GI cereal. Previous research has argued that a low GI breakfast can improve cognitive performance when compared to a high GI breakfast (e.g. Mahoney et al., 2005). The findings from the present study did not support this suggestion. The findings did not show any significant main effects of breakfast. There was however, a significant interaction between assessment time and breakfast on reaction time for correct responses on the choice reaction time task. Further analysis on this interaction did however, not reveal any significant interactions between the breakfasts at any of the test times suggesting that the interaction effect is very fragile. Examining the means and Fig. 4.1, however, it appears that the interaction is due to an improvement in performance for the No Breakfast condition at 11.40am. This result is in the opposite direction of what would be expected based on previous research which argues that performance after No Breakfast will decline.

Upon closer inspection of Tables 4.4 and 4.5 and Fig. 4.1, it is noteworthy that performance was stable throughout the morning following Coco Pops and All Bran whereas this was not the case when children did not consume any breakfast. Previous research has suggested that children’s performance tends to decline throughout the morning (Muthayya et al. 2007; Wesnes et al., 2003). It could be argued that the stable performance after the consumption of both Coco Pops and All Bran represents a positive effect on performance in that it prevented performance from declining throughout the morning. However, the improvement for the No Breakfast condition which was in the opposite direction of what was expected makes such an explanation hard to justify.

Overall, the current results do not support previous research arguing that breakfast consumption can improve cognitive performance compared to breakfast omission (e.g. Wesnes et al., 2003) or that a low GI breakfast is beneficial to performance compared to a high GI breakfast (e.g. Mahoney et al., 2005).

CHAPTER 5: The Influence of Glycaemic Index of Breakfast Cereal on Children's Attention and Memory

5.1. Introduction

Due to the age-related changes observed in both cognitive function (Swanson, 1999; Rebok et al., 1997) and in cerebral glucose utilisation (Chugani, 1987; 1994), it is possible that food consumption will have a differential effect on cognitive performance in children depending on their age. Wesnes et al., (2003) investigated the effects of breakfast consumption in children aged 9 to 16 years of age. The authors did find positive effects of breakfast on some of their attention and memory measures but not on others. The age range considered by Wesnes et al. is very wide. Within this age range the younger children are likely to still have very high rates of cerebral glucose utilization whereas this will have reached adult levels in the older children. As mentioned in chapter 1, cognitive performance changes with age and within the range of 9 to 16 years there are improvements in both memory and attention (Gathercole, 1999; Welsh et al., 1991; Rebok et al., 1997; Swanson, 1999). Wesnes et al.'s results could have been confounded by the fact that they did not take age into consideration as age was not included as a factor or as a co-variate. It is possible that the results would have been different if they had for example split the children into age groups similar to Mahoney et al (2005). Mahoney et al. (2005) investigated the effects of breakfast composition (GI) on cognitive performance in children aged 6 to 11 years. Mahoney et al. specifically investigated age-related effects in two separate experiments. In their first experiment the children were 9-11 years old and in their second experiment the children were 6-8 years old. Mahoney et al. found significant effects of breakfast compared to no breakfast in both age groups. They also found effects of breakfast composition in both age groups (better performance after low GI breakfast) although this effect was observed on more variables for the younger age group suggesting that it is possible that the younger children are more susceptible to nutritional manipulations.

Earlier chapters in the current thesis have not tested for age differences as the age ranges have been reasonably small (12-13 years in Chapters 2 and 3; 8-10 years in chapter 4). Therefore, to further investigate the effects of breakfast and GI on children's cognitive performance it was decided to include a wider age range (6-11 years) in the current study in order to examine whether breakfast and GI have different effects on different age groups. In order to make comparisons with Mahoney et al. (2005), the children were further divided into 2 age groups: 6-8 years and 9-11 years, to examine whether there were any differential effects of breakfast on the two age groups.

To further evaluate the effects of the glycaemic index of breakfast on children's attention and memory, the current study set out to replicate Chapter 4 with the addition of an age factor. The current study also employed a more tightly controlled design where the breakfast variable was changed to a within subjects variable so that all children received all three breakfasts (high GI, low GI and no Breakfast) and hence, acted as their own controls.

Based on previous literature it was hypothesised that children's performance on the attention and memory tasks would be better following the consumption of the low GI breakfast compared to the high GI breakfast and breakfast omission. Although Mahoney et al.'s results suggest that the children aged 6-8 years might be more susceptible to the effects of the GI of breakfast, no specific prediction was made with regards to an age effect.

5.2. Method

5.2.1. Design

The design used in the current study was a mixed measures design (Breakfast x Assessment Time x Age Group). Breakfast was a within subjects variable with three levels: High GI (Coco Pops), Low GI (All Bran) and No Breakfast. Assessment Time was also a within subjects variable with three levels: 9.40am, 10.40am and 11.40am. Age group was a between subjects variable with two levels: 6-8 years and 9-11 years. The dependent variable was scores on the cognitive tests.

5.2.2. Participants

Thirty children aged between 6 and 11 years were recruited from the North East of England in an area encompassing a range of socio-economic backgrounds. The study was approved by the Northumbria University School of Psychology and Sports Sciences Ethics Committee. There were 15 boys and 15 girls. To be able to make comparisons with Mahoney et al.'s (2005) findings in relation to age effects, children were divided into two age groups: younger children aged 6-8 years (7 boys, 8 girls) and older children aged 9-11 years (8 boys, 7 girls) (see Table 5.1 for demographic details). In the current study BMI was not used as a variable but used to recruit a sample of children that fell within the 'normal' range of BMI as identified by Cole et al. (2000).

Table 5.1: Mean age and age range for 6-8 year-olds and 9-11 year-olds and gender split with BMI for each age group.

Age Group	Gender	N	BMI	Mean age (yrs:mths)	Age range (yrs:mths)
6-8 years	Boys	7	15.4	7:10	6:0 – 8:9
	Girls	8	18.3		
9-11 years	Boys	8	15.4	10:3	9:3 – 11:3
	Girls	7	18.3		

Participants were recruited through local primary and middle schools. All participating head teachers consented to the study taking place in their school prior to commencement of the study. Informed consent was also obtained from parents of the participating children and verbal consent was given from each participating child on the day of testing. All children were fasted from 10pm the night before testing (with the exception of being allowed to drink water). The children were given stickers for taking part and participating schools were given a £10 Waterstones voucher as a token of appreciation.

5.2.3. Cognitive Test Battery

The same cognitive test battery, CAMBA (Children's Attention and Memory) that was employed in chapters 2, 3 and 4 was used in the current study. The battery consisted of: Simple Reaction Time, Choice Reaction Time, Corsi Blocks, Continuous Attention Task and Odd-one-Out.

5.2.4. Treatments

All children were provided with the high GI cereal Coco Pops, the low GI cereal All Bran and No Breakfast on three consecutive days, with the order of presentation counterbalanced. For both cereals children were given a 35g portion accompanied by 125ml semi-skimmed milk. Approximately 10 minutes was allowed for breakfast consumption. Nutritional characteristics of each treatment condition are given in Table 5.2.

Table 5.2: Nutritional characteristics of 35g of All Bran and 35g Coco Pops. The GI value is taken from an international table of glycaemic index (Foster Powell et al., 2002).

Nutrient	Units	All Bran	Coco Pops	No Breakfast
Energy	kcal	98	133	
Protein	g	4.9	1.6	n/a
Fat	g	1.6	0.9	All values=0
Fibre	g	9.5	0.7	
Carbohydrate	g	16.1	29.8	
Sugars	g	2.45	11.9	
Starch	g	10.85	17.85	
Glycaemic Index	GI	42	77	

5.2.5. Procedure

Each child was required to attend three active study days conducted on consecutive days so that each child took part in all three treatment conditions on three consecutive days. Children were tested in groups of up to twelve in a quiet area of their school. Upon arrival on the first study day children were randomly allocated to a treatment group following a Latin Square design, counterbalancing the order of treatments across the three active study days. To familiarise the children with the tests, the experimenter ran through the entire test battery with the children on the first study day as a practice session. These data were not recorded for analyses.

The three study days were identical except on day one when children had a practice session. Baseline (pre-breakfast) measures were taken at 9.00am after an overnight fast. Breakfast was given at 9.30am and the children were tested again at 9.40am, 10.40am and 11.40am. Each test session lasted approximately 15 minutes.

5.2.6. Statistics

All data was analysed using SPSS.

For each cognitive measure, change from baseline scores was analysed by a three-way mixed ANOVA [breakfast (All Bran, Coco Pops and No Breakfast) x assessment time (9.40am, 10.40am and 11.40am) x age group (6-8yrs and 9-11yrs)]. Breakfast and assessment time were within subjects variables and age group was a between subjects variable.

Bonferroni corrected post hoc pairwise comparisons were provided where there were significant differences ($p<0.05$) and further one-way ANOVAs were carried out to elucidate any significant interactions. Due to the high number of possible interactions, only significant interactions are reported in the results.

As mentioned in chapter 4, there is some debate as to whether it is better to analyse pre-test – post-test data by ANCOVA on raw scores or ANOVA on change from baseline scores (e.g. Dimitrov & Rumrill, 2003). Results from alternative analysis by ANCOVA are again presented in Appendix 10 and it can be seen that this analysis did not alter the results a great deal.

5.3. Results

Mean scores on baseline and for each time point are presented in Table 5.3 and mean change from baseline scores for each condition by age group at each assessment time are presented in Table 5.4. Unfortunately an error occurred during the recording of the Choice RT Test (correct responses) and the Continuous Attention Task test so no results are reported for these tests. Due to the number of interactions in the current study, interactions are only reported if significant. For plots of raw data for each measure and a list of all F-values see appendices 8 and 9 respectively.

5.3.1. Simple Reaction Time

Analysis showed no significant main effects of Breakfast ($F(2,56) = 1.110$; $p=0.896$) or Age Group ($F(1,28) = 0.263$; $p=0.612$). There was, however, a significant main effect of Assessment Time ($F(2,56) = 3.229$; $p=0.047$). Pairwise comparisons revealed significant difference between performance at 9.40am (94.34) and 10.40am (11.05) with better performance at 10.40am (Fig. 5.1).

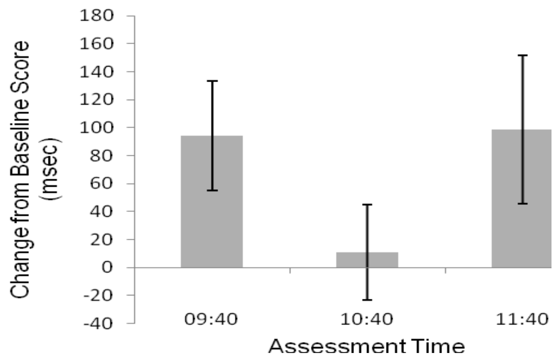


Figure 5.1: Effect of assessment time on change from baseline scores on simple reaction time.

Table 5.3: Mean scores (SD) on baseline and at each assessment time for each breakfast condition by age group.

Measure	Breakfast	Age Groups	n	Baseline	9.40am	10.40am	11.40am
Simple RT (msec)	Coco Pops	6-8yrs	15	671.71 (452.70)	702.09 (589.59)	669.17 (472.63)	749.84 (756.24)
		9-11yrs	15	510.26 (206.08)	656.36 (605.72)	590.01 (324.38)	572.91 (208.96)
	All Bran	6-8yrs	15	509.77 (212.66)	634.30 (459.21)	454.17 (285.12)	712.25 (611.37)
		9-11yrs	15	476.08 (106.49)	636.11 (365.84)	496.86 (139.90)	564.70 (205.38)
	No Breakfast	6-8yrs	15	519.68 (292.79)	535.22 (308.90)	450.99 (283.04)	638.53 (343.13)
		9-11yrs	15	454.61 (125.80)	544.14 (147.95)	547.20 (328.58)	495.47 (181.68)
	Total		30		618.04 (53.96)	534.73 (47.19)	622.28 (61.87)
Choice RT (msec for correct responses)	Coco Pops	6-8yrs	15	1043.80 (544.96)	1197.58 (879.78)	1034.76 (486.52)	1424.09 (1579.84)
		9-11yrs	15	699.47 (145.45)	879.94 (426.51)	758.08 (234.40)	796.88 (305.20)
	All Bran	6-8yrs	15	863.50 (296.13)	927.66 (535.80)	926.82 (542.70)	1250.86 (1047.78)
		9-11yrs	15	789.81 (223.57)	937.33 (492.59)	813.05 (314.04)	813.14 (162.83)
	No Breakfast	6-8yrs	15	993.28 (585.81)	1796.18 (3189.17)	1191.65 (1021.13)	1303.93 (1324.12)
		9-11yrs	15	734.83 (163.83)	811.70 (240.05)	791.35 (192.84)	765.48 (179.73)
	Total		30		1091.73 (156.78)	919.28 (81.91)	1059.06 (166.25)
Corsi Blocks (no. correct)	Coco Pops	6-8yrs	15	10.87 (3.18)	8.33 (5.29)	9.60 (5.05)	8.40 (5.59)
		9-11yrs	15	15.07 (2.25)	14.07 (3.22)	13.93 (3.86)	13.87 (2.26)
	All Bran	6-8yrs	15	10.47 (4.66)	8.27 (4.76)	9.67 (3.72)	8..80 (3.98)
		9-11yrs	15	14.20 (3.30)	13.27 (3.41)	13.87 (3.27)	12.93 (3.37)
	No Breakfast	6-8yrs	15	10.33 (4.29)	8.53 (4.91)	9.67 (3.71)	8.20 (4.86)
		9-11yrs	15	15.13 (2.72)	14.67 (3.66)	13.87 (2.67)	13.27 (2.46
	Total		30		11.19 (0.684)	11.767 (0.626)	10.74 (0.614)
Odd-one-Out Recall (no. correct)	Coco Pops	6-8yrs	15	14.33 (6.03)	8.67 (4.24)	9.67 (6.15)	8.07 (5.08)
		9-11yrs	15	20.07 (6.82)	12.53 (5.94)	12.67 (4.81)	12.80 (6.96)
	All Bran	6-8yrs	15	12.80 (4.90)	7.87 (4.63)	9.20 (3.76)	8.27 (4.45)
		9-11yrs	15	18.80 (6.05)	12.47 (5.44)	13.20 (5.70)	11.40 (5.60)
	No Breakfast	6-8yrs	15	13.33 (6.59)	7.33 (5.81)	9.07 (5.47)	7.47 (4.75)
		9-11yrs	15	17.07 (7.42)	11.93 (5.22)	11.73 (5.26)	11.67 (5.81)
	Total		30		10.13 (0.318)	10.92 (0.296)	9.94 (0.331)

Table 5.4: Mean change from baseline scores (SD) for each condition and age group across assessment time. Significant effects are indicated in the last column (Ti = Time (assessment time), *p<0.05, **p<0.005).

Measure	Breakfast	Age Group	n	Change from baseline				Significant effects
				9.40 am	10.40 am	11.40 am	Total	
Simple RT (msec)	Coco Pops	6-8yrs	15	30.37(690.34)	-2.54 (567.84)	78.13 (851.77)	65.74 (87.52)	Ti*
		9-11yrs	15	146.10 (412 (47)	79.75 (179.03)	62.65 (198.99)		
	All Bran	6-8yrs	15	124.53 (433.11)	-55.60 (312.29)	202.48 (591.88)	90.14 (50.31)	
		9-11yrs	15	160.03 (314.73)	20.78 (88.92)	88.62 (162.00)		
	No Breakfast	6-8yrs	15	15.53 (363.18)	-68.69 (388.95)	118.85 (331.23)	48.11 (44.37)	
		9-11yrs	15	89.53 (136.13)	92.59 (260.80)	40.86 (189.57)		
		Total	30	94.35 (39.24)	11.05 (34.02)	98.60 (53.28)		
Choice RT (msec for correct responses)	Coco Pops	6-8yrs	15	153.79 (724.70)	-9.04 (299.79)	380.29 (1287.72)	143.59 (88.21)	-
		9-11yrs	15	180.47 (307.51)	58.62 (176.14)	97.41 (246.87)		
	All Bran	6-8yrs	15	64.16 (393.13)	63.31 (395.22)	387.36 (878.14)	118.15 (64.07)	
		9-11yrs	15	147.52 (338.98)	23.24 (170.34)	23.34 (136.70)		
	No Breakfast	6-8yrs	15	802.90 (2977.09)	198.37 (699.78)	310.64 (1039.43)	245.99 (131.78)	
		9-11yrs	15	76.87 (136.40)	56.52 (160.59)	30.64 (100.06)		
		Total	30	237.62 (123.80)	65.95 (45.04)	204.95 (128.25)		
Corsi Blocks (no. correct)	Coco Pops	6-8yrs	15	-2.53 (4.21)	-1.27 (3.05)	-2.47 (3.91)	-1.77 (0.51)	Ti*
		9-11yrs	15	-1.00 (2.90)	-1.13 (3.16)	-2.20 (2.83)		
	All Bran	6-8yrs	15	-2.20 (2.78)	-0.80 (3.34)	-1.67 (2.53)	-1.20 (0.54)	
		9-11yrs	15	-0.93 (3.58)	-0.33 (3.60)	-1.27 (3.81)		
	No Breakfast	6-8yrs	15	-1.80 (3.45)	-0.67 (2.66)	-2.13 (2.75)	-1.37 (0.50)	
		9-11yrs	15	-0.47 (3.54)	-1.27 (3.73)	-1.87 (2.23)		
		Total	30	-1.49 (0.42)	-0.91 (0.32)	-1.93 (0.35)		
Odd-one-Out Recall (no. correct)	Coco Pops	6-8yrs	15	-1.60 (3.00)	-0.60 (4.32)	-2.20 (4.90)	-2.00 (0.578)	Ti**
		9-11yrs	15	-2.67 (2.77)	-2.53 (3.16)	-2.40 (3.58)		
	All Bran	6-8yrs	15	-0.80 (3.38)	0.53 (4.31)	-0.40 (4.87)	-0.80 (060)	
		9-11yrs	15	-1.27 (2.99)	-0.53 (3.11)	-2.33 (3.27)		
	No Breakfast	6-8yrs	15	-2.27 (4.68)	-0.53 (3.11)	-2.13 (2.37)	-1.50 (0.53)	
		9-11yrs	15	-1.20 (2.93)	-1.40 (2.44)	-1.47 (4.78)		
		Total	30	-1.63 (0.32)	-0.84 (0.30)	-1.82 (0.33)		

5.3.2. Choice Reaction Time

5.3.2.1. Percentage correct responses

An error occurred in the recording of the percentage correct responses and hence no results are presented for this measure.

5.3.2.2. Reaction time for correct responses

The results showed no significant main effects of Assessment Time ($F(2,56) = 1.033$; $p=0.362$), Breakfast ($F(2,56) = 0.784$; $p=0.462$) or Age Group ($F(1,28) = 1.448$; $p=0.239$).

5.3.3. Corsi Blocks

Analysis showed a significant main effect of Assessment Time ($F(2,56) = 4.910$; $p=0.011$). Pairwise comparisons revealed a significant difference between 10.40am (-0.91) and 11.40am (-1.9) with better performance at 10.40am (Fig. 5.2). There was no significant main effect of Breakfast ($F(2,56) = 0.334$; $p=0.718$) or Age Group ($F(1,28) = 0.826$; $p=0.371$).

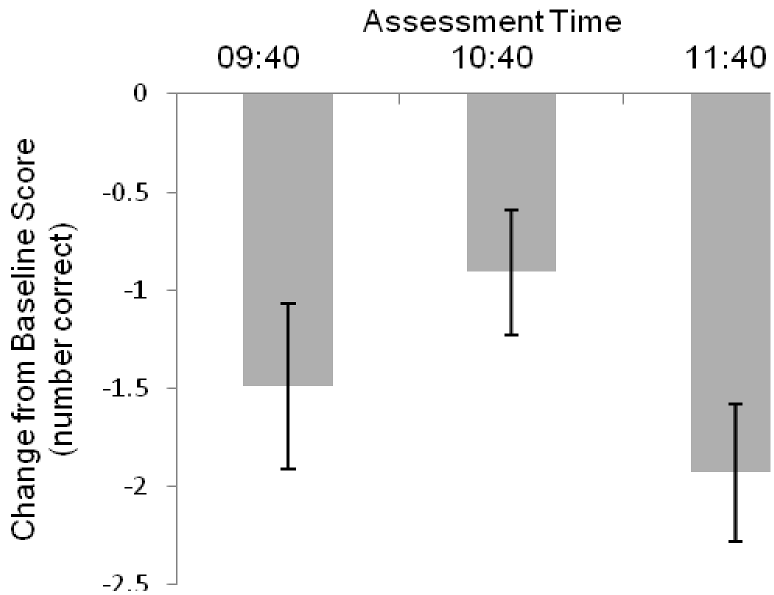


Figure 5.2: Effects of assessment time on change from baseline on the corsi blocks test

5.3.4. Continuous Attention Task

5.3.4.1. Reaction time for correct responses

During the recording of the percentage correct responses and error occurred, hence, no results are presented for this measure.

5.3.4.2. d'

An error occurred in the recording of the percentage correct responses so there are no results to report for this measure.

5.3.5. Odd-one-Out

The results revealed no significant main effects of Breakfast ($F(2,56) = 0.962$; $p=0.338$) or Age Group ($F(1,28) = 1.424$; $p=0.243$). There was, however, a significant main effect of Assessment Time ($F(2,56) = 6.761$; $p=0.002$). Pairwise comparisons showed a significant difference between performance at 9.40am (-1.63) and 10.40am (-0.84) with better performance at 10.40am (Fig. 5.3).

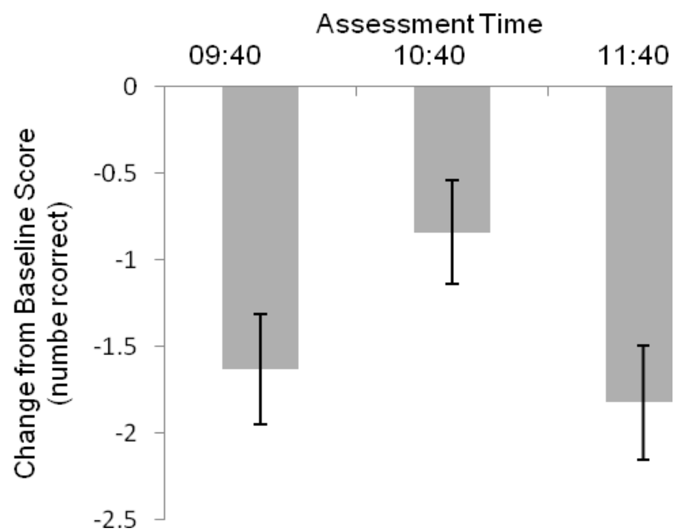


Figure 5.3: Effects of assessment time on change from baseline scores on the odd-one-out task.

5.4. Discussion

The current study set out to investigate whether the glycaemic index of breakfast cereals has an effect on children's attention and memory and whether such potential effects may be different depending on children's age. The results showed no significant effects of the GI of breakfast or age. There was, however, a significant main effect of Assessment Time on Simple Reaction Time, Corsi Blocks and Odd-one-Out.

The current study does not support the suggestion that breakfast consumption or GI of breakfast can reduce the decline observed in cognitive performance throughout the morning in children as there was no significant effect of GI of breakfast. In fact, the current results did not show a significant decline in children's performance except from on the Corsi Blocks measure. The current results revealed a significant main effect of Assessment Time on Simple Reaction Time, Corsi Blocks and Odd-one-Out However, performance on Simple Reaction Time and Odd-one-Out both showed a significant improvement in performance from 09.40am to 10.40am whereas on Corsi Blocks there was a significant decline in performance from 10.40am to 11.40am. On closer inspection of the results on all of the measures, it can be seen that there was an improvement in performance from 09.40am to 10.40am and then a decrease in performance from 10.40am to 11.40am on all of the measures (Simple RT, Corsi Blocks, Odd-one-Out and Choice RT). However, only some of these improvements/decrements were significant (as described above). So although not significant on all measures, an examination of the means and graphs suggest that there was improvement in performance 1 hour after breakfast consumption with a decline in performance 2 hours after consumption.

Contrary to Wesnes et al. (2003) and Muthayya et al. (2007) the current results do not support the notion that there is a decline in children's performance throughout the morning. Instead, an improvement in performance was observed from 9.40am to 10.40am. It is uncertain why such an improvement was observed at 60 minutes post-breakfast. Referring back to Fig. 1.5 (chapter 1), which shows blood glucose response following intake of high and low GI food, it can be seen that at 60 minutes blood glucose levels are still higher than baseline levels after both high and low GI. When comparing the results to glucose studies in children one previous study found improved reaction time and more time spent quietly concentrating following glucose (25g) at approximately 60 minutes post-dose (Benton et al., 1987). Benton & Jarvis (2008) also found improved performance following a glucose load (25g). However, these effects were observed only 15 minutes post-dose. Furthermore, Wesnes et al. (2003) did not find any improvement in cognitive performance following glucose (38.5g). It also has to be noted that, as discussed in chapter 1, there were a number of possible confounding variables in these studies (e.g. lack of dietary control prior to treatment). There is a possibility that the improved performance at 60 minutes post-breakfast is due to raised blood glucose levels but that the test battery employed is not sensitive enough to detect subtle differences in performance. An alternative interpretation is that the improved performance is due to practice effects and that the fact that there was a practice session prior to testing on day one and not the other days. However, if there was a practice effect one would expect to also see improved performance at 120 minutes post-breakfast (11.40am) but this was not the case. Another possibility for the improved performance at 60 minutes is that the children have either eaten or drank something during the time between finishing the 9.40am session and starting the 10.40am session which has confounded the results. Although they were asked to not consume anything other than water, what the children were doing in between the test sessions were not controlled for as they had to continue their usual school routine between the sessions.

Studies have suggested that both attention (Rebok et al., 1997) and memory (Gathercole, 1999) performance increase up to approximately 10-12 years of age with a particularly rapid growth in capability up to about 8 years of age. Furthermore, it has also been suggested that the effects of breakfast consumption on cognitive performance may be greater in children due to metabolic factors such as cerebral glucose utilisation (Mahoney et al., 2005). Due to these factors, the current study examined whether the effects of breakfast would have a different effect on children aged 6-8 years compared to children aged 9-11 years. However, contrary to Mahoney et al. (2005) who found effects of GI on more measures for younger children (6-8 years) than older children (9-11 years), the results from the current study did not reveal any significant differences between the younger and the older children. Lack of such age effects further support the idea that the test battery employed in the current study is not sensitive enough.

It is worth noting, however, that Mahoney et al. (2005) tested their two groups of children in two separate experiments. They tested the 9 to 11 year old children in Experiment 1 and the 6 to 8 year olds children in Experiment 2. Although all tests and procedures were the same for the two experiments, two of the tests, Spatial Learning and Verbal Memory, were altered to make them easier and to make them, according to the authors, age appropriate. By altering the tasks, it has more than likely made them more age appropriate but it has also changed the cognitive demand of the tasks. Some researchers (e.g. Kennedy & Scholey, 2000) have argued that the effects of glucose on cognitive performance are dependent on the cognitive demand of the tests and that glucose preferentially targets tasks that require a higher mental effort. One explanation for the non-significant findings in the current study could be that the tasks do not have high enough cognitive loads for GI to have an effect. The tests in the current study were all different from those used by Mahoney et al. (2005) apart from the Continuous Performance Task (referred to as visual attention by Mahoney et al.). It is possible that the tasks used by Mahoney et al. had higher cognitive demands than the tasks employed in the current study. Hence, it could be that the failure to detect an effect of GI in the current study is due to a lack of sensitivity of the assessment battery in that the tasks are not cognitively demanding enough to detect subtle effects of GI on cognitive performance.

CHAPTER 6: The Effect of Breakfast on Cognitive Functioning in School Children

6.1. Introduction

A number of studies have examined the effects of breakfast consumption on cognitive performance in children (for reviews, see Rampersaud et al., 2005; Hoyland et al., 2008, see Appendix 6 for a summary of previous breakfast studies). Some of these studies have shown a benefit in performance following breakfast consumption compared with breakfast omission. Wesnes et al. (2003) investigated the effects of the consumption of two breakfast cereals compared to glucose intake and breakfast omission in children aged 9 to 16 years of age. They found that there was a significantly smaller decline in performance for Secondary Memory (referred to as Quality of Episodic Secondary Memory in Wesnes et al., 2003) and Speed of Attention (referred to as Power of Attention in Wesnes et al., 2003) following the consumption of the two breakfast cereals compared with the consumption of the glucose drink and no breakfast. More recently, researchers have started investigating the effects of different types of breakfast on children's cognitive performance, rather than just comparing breakfast consumption to breakfast omission. Mahoney et al. (2005) examined the effect of breakfast composition on attention and memory in children and found that a low GI breakfast was more beneficial to performance than a high GI breakfast or no breakfast, particularly for younger children (6-8 years). Benton et al. (2007) investigated the effect of the glycaemic load of breakfast on attention and memory in children aged 5 to 7 years of age. They found that the children's memory and sustained attention were better after the consumption of a breakfast with low glycaemic load and also that these children showed fewer signs of frustrations and spent more time on task.

It should be noted, however, that significant effects of breakfast or breakfast type (e.g. GI) are usually only found on some of the outcome measures in a study suggesting that breakfast preferentially affects different cognitive functions. Wesnes et al. (2003), for example, found significant effects on Secondary Memory and Speed of Attention but not on Speed of Memory, Accuracy of Attention, and Working Memory (the three factors, Speed of Attention, Accuracy of Attention and Secondary Memory are referred to as Power of Attention, Continuity of Attention, and Quality of Episodic Secondary Memory, respectively, in Wesnes et al., 2003). Furthermore, the results from research investigating the effects of breakfast on cognitive performance show effects on different cognitive domains. Some studies, for example, have found significant effects on attention (Benton & Jarvis, 2007; Wesnes et al., 2003) whereas others have found effects on memory (Vaisman, 1996; Widenhorn-Müller, 2008). Hence, it is difficult to make firm conclusions as to which cognitive functions, if any at all, are affected by breakfast consumption whether comparing different types of breakfast or comparing to breakfast omission.

The studies in Chapters 4 and 5 of the current thesis set out to further investigate the effects of the glycaemic index (GI) of breakfast on attention and memory in children. The two studies did not find any effects of GI on children's cognitive performance. Neither did they find any effects of age or any conclusive effects of assessment time. One of the explanations proposed for the lack of significant results in chapter 5 was that the cognitive test battery employed was not sensitive enough to detect subtle changes in performance or, alternatively, the battery was not cognitively demanding enough to detect nutritional manipulations. It has been argued that a cognitive task is more susceptible to the effects of glucose when the cognitive demand of the test is high (Scholey et al., 2001). It has furthermore been argued that during performance of a task with high cognitive demand, there is a steeper drop in blood glucose than what is observed during a less demanding task (Scholey et al., 2001). Kennedy & Scholey (2000) suggested that there is a relationship between improved task performance and changing blood glucose levels following glucose intake in that decreasing levels of blood glucose can predict performance on a number of cognitive tasks. It is suggested that the fall in blood glucose observed during tasks with high demand, increases the delivery of glucose to the brain which in turn affects cognitive performance.

Kennedy & Scholey (2000) investigated the relationship between increased demand on cognitive tasks, glucose intake, heart rate and cognitive performance. In this placebo-controlled cross-over study, Kennedy & Scholey assessed the effects of a glucose drink (25g) on cognitive performance and heart rate on three tasks which differed in cognitive demand. The three tasks were Serial Sevens, Serial Threes and Verbal

Fluency. Participants rated the Serial Sevens as the most mentally demanding task, followed by the Verbal Fluency task with the Serial Threes task as the least demanding task. Intake of the glucose drink, compared to placebo, significantly improved performance only on the task that was rated as most demanding, the Serial Sevens task. There was also a trend toward improved performance on the Verbal Fluency task which was rated as the second most demanding task by the participants.

Similarly, Scholey et al. (2001) assessed the effects of cognitive demand on blood glucose. This counter-balanced cross-over study directly examined the effects of cognitive demand on blood glucose levels by comparing performance on a Serial Sevens task (high demand) and a finger tapping control task (low demand) in a glucose condition (25g) and a placebo condition. Scholey et al. found that the fall in blood glucose levels was greater following the demanding Serial Sevens task compared to the control task regardless of whether it was in the glucose or placebo condition. They also found that this fall in blood glucose was greater in the glucose condition compared to the placebo condition, regardless of task. Furthermore, Scholey et al. (2001) also examined the effect of glucose consumption on performance on three tasks with differing cognitive demands. Consistent with the results of Kennedy et al. (2000), Scholey et al. (2001) found that compared to placebo, the glucose intake significantly improved performance on the Serial Sevens task, that there was a trend towards improvement after glucose intake on a verbal fluency task and that there was no effect on a word memory task. In other words, the results showed that the more cognitively demanding tasks were more influenced by the glucose intake.

The results from studies investigating the interactions between glucose intake, cognitive demand and performance, suggests that glucose intake preferentially targets cognitive tasks with a high cognitive demand. To further investigate the effects of the GI of breakfast, the current study employed a cognitive battery (CDR) which is more cognitively demanding than the CAMBA battery employed in the earlier chapters in this thesis. Although the cognitive demand of neither the CAMBA battery nor the CDR battery was measured in the current thesis, the CDR battery was considered more demanding as it includes more trials within most of the individual tests and because the whole battery included more tasks (11 compared to 5 in the CAMBA battery) and lasted longer (25min compared to 15 min for CAMBA). Mulder (1986) suggested that the increased cognitive demand of a task can be due to factors such as novelty, time pressure, higher cognitive load, response inhibition and multi-tasking. By employing a battery which requires more mental effort it is hoped that any possible effects of GI will be observable. The no breakfast condition was abandoned in the current study due to negative comments from some children and teachers with regards to this condition in Chapter 5. Some of the children for example, when they received no breakfast, had comments such as “I am so hungry” and “I think I’m going to faint”. Some comments overheard from teachers were things such as “they’ve not had any breakfast all morning!” and one teacher commented directly on how she could not understand how it was ethical to let the children go without food all morning. Such comments from the children are more than likely over exaggerated but combined with the comments from the teachers it was decided to leave the no breakfast condition out of the current study. Although GI was not found to have a differential effect on younger and older children in Chapter 5, the current study included age as a factor to further examine the notion that younger children may be more susceptible to the effects of GI. The age groups were kept the same as in chapter 5 (6-8 years and 9-11 years) as was the post-breakfast test times (9.40am, 10.40am and 11.40am) and the remaining two breakfast conditions (All Bran – low GI and Coco Pops – high GI).

The main aim of the current study was to investigate the effects of GI of breakfast on children's attention and memory. The secondary aim was to examine whether GI differentially affects younger and older children. The current study also indirectly examined whether the more cognitively demanding test battery was more sensitive to the effects of GI of breakfast. It was hypothesised that performance would be better after the consumption of the low GI breakfast compared to the high GI breakfast. With regards to age, no specific hypothesis was made. Although not directly assessed, it was predicted that the potential effects of GI on performance were more likely to be revealed with the current more demanding test battery compared to the CAMBA battery employed earlier in the thesis.

6.2. Method

6.2.1. Design

The current study employed a mixed measures design with three independent variables: Breakfast (GI) x Assessment Time x Age Group. Breakfast was a repeated measures variable and had two levels (high GI and low GI). Assessment Time was also a repeated measure variable with three levels (9.40am, 10.40am and 11.40am). Age group was a between subjects factor with two levels (6-8 year-olds and 9-11 year-olds). The dependent variables were the scores on the cognitive test battery.

6.2.2. Participants

Sixty-five children aged between 6 and 11 years were recruited from an area in the North East of England encompassing schools from a range of socio-economic areas. There were 27 boys and 38 girls. One boy did not finish his breakfast (All Bran) and his results were excluded from analysis. The remaining children were divided into two age groups: younger children aged 6-8 years (29: 12 boys, 17 girls) and older children aged 9-11 years (14 boys, 21 girls) (see Table 6.1 for demographic details). These age groups were chosen to keep consistent with chapter 5 and Mahoney et al. (2005). As with the previous chapters, BMI was not used as a variable in the current study but used to recruit a sample of children that fell within the 'normal' range of BMI as identified by Cole et al. (2000).

Table 6.1: Mean age and age range for 6-8 year-olds and 9-11 year-olds and gender split with BMI within each age group.

Age Group	Gender	N	BMI	Mean age (yrs:mths)	Age range (yrs:mths)
6-8 years	Boys	12	16.9	7:8	6:8 – 8:11
	Girls	17	16.0		
9-11 years	Boys	14	17.3	10:6	9:3 – 11:7
	Girls	21	19.5		

The study was approved by the Northumbria University School of Psychology and Sports Sciences Ethics Committee. Prior to commencement of the study all head teachers of participating schools consented to the study taking place in their school. Informed consent was also obtained from parents of the participating children and verbal consent was given from each participating child on the day of testing. All children were fasted from 10pm the night before testing (except from being allowed to drink water). The children were given stickers for taking part and participating schools were given a £10 Waterstones voucher as a token of appreciation.

6.2.3. Measures

6.2.3.1. Cognitive Drug Research (CDR) Assessment Battery

Attention and memory was assessed using the Cognitive Drug Research (CDR) Computerised Assessment Battery (Wesnes et al., 2000; 2003). The

CDR battery has previously demonstrated a sensitivity to the improvements and decrements seen in cognitive performance following a number of food components and dietary supplements (e.g. Haskell et al., 2005; Kennedy et al., 2004; Scholey and Kennedy, 2004; Wesnes et al., 2000) and has also been used to investigate the effects of breakfast in children (Wesnes et al., 2003). The children's version of the CDR battery utilised in the current study consisted of eleven tasks which were presented in the following order: Word presentation; Immediate word recall; Picture presentation; Simple reaction time; Digit vigilance; Choice reaction time; Spatial working memory; Numeric working memory; Delayed word recall; Delayed word recognition; Delayed picture recognition (the tasks are described in more detail below).

All the tests were presented on laptops with responses recorded via a two-button (YES/NO) response box, except for the two word recall tasks which were paper and pencil tasks. The entire battery took approximately 25 minutes to complete with parallel forms presented at each test session.

To allow comparison with Wesnes et al. (2003), the above measures were collapsed into the following five primary cognitive factors: Speed of Attention, Speed of Memory, Accuracy of Attention, Secondary Memory and Working Memory. These factors have been calculated and validated by CDR (Wesnes et al. 2000) and have previously been used in studies measuring the effects of foods and supplements on cognitive performance both in adults (e.g. Kennedy et al., 2000) and children (e.g. Wesnes et al., 2003). As the factors have been previously derived these factor scores were not calculated in the current study but for each factor a number of the sub-tests were merely combined following specific formulas provided by CDR.

6.2.3.1.1. Word Presentation

Fifteen words were presented on the screen one at the time. The words were matched for frequency and concreteness. The stimulus duration was one second as was the inter-stimulus interval. The children were instructed to look at the words and try to remember them as they would have to recall them later.

6.2.3.1.2. Immediate Word Recall

Immediately after the word presentation ended, the children were asked to write down as many of the words as they could remember. They were told that correct spelling was not important. They had sixty seconds to write down as many words as possible. The dependent measures were words correctly recalled (number of and %), number of intrusions and number of errors. Intrusions were recalled words that had appeared in an earlier word list but not the current word list and errors were words that had not appeared in any lists.

6.2.3.1.3. Picture Presentation

Twenty pictures were presented, one at the time, on the screen. The stimulus was displayed for 3 seconds and the interstimulus interval was 1 second. The children were instructed to look at the pictures and told that they would be asked to recall them later.

6.2.3.1.4. Simple reaction time

The word ‘yes’ was presented in the middle of the screen. The children were instructed to press the yes button on the response pad as quickly as possible every time the word appeared on the screen. Fifty stimuli were presented with a varying interstimuli interval between 1 and 3.5 seconds. The dependent measure was reaction time (msec).

6.2.3.1.5. Digit vigilance

A random target digit was continuously displayed on the right hand side of the screen. A continuous series of digits was then presented in the middle of the screen one at the time. The children were instructed to press the ‘yes’ button on the response box as quickly as possible when they saw the same digit as the target digit in the middle of the screen. The digits in the middle were presented at a rate of 80 digits per minute. There were 45 stimulus –

target matches and the task lasted three minutes. The dependent measures were targets detected (%), speed (msec) and number of false alarms.

6.2.3.1.6. Choice reaction time

Either the word ‘yes’ or the word ‘no’ were presented in the middle of the screen with an interstimuli interval between 1 – 3.5 seconds. The children were instructed to press the ‘yes’ button when ‘yes’ appeared on the screen and the ‘no’ button when ‘no’ appeared on the screen. There were 50 trials and the dependent measures were accuracy (%) and reaction time (msec).

6.2.3.1.7. Spatial Working Memory

A picture of a house with nine windows was displayed on the screen with four of the windows lit up. The picture was displayed on the screen for 15 seconds and the children were instructed to remember which of the windows were lit. A series of thirty-six pictures of the same house, but with only one window lit, was then displayed on the screen one at the time. For each house the children were instructed to press the ‘yes’ button if the lit window was lit in the original house and to press the ‘no’ button if the lit window was not lit in the original house. They were asked to make their response as quickly as possible. The dependent measures were accuracy (%) for both original (window lit in original house) and new (window not lit in original house) stimuli and reaction time (msec). A sensitivity index (SI) measure was also derived from the children’s responses. SI ranged from -1 to 1 where -1 is when every stimulus is incorrectly identified, 0 is random performance and 1 is where every stimulus were correctly identified)

6.2.3.1.8. Numeric Working Memory

Five digits were presented one at the time in the middle of the screen. The children were instructed to remember the numbers. A series of 30 digits were then presented one at the time. For each digit the children had to press the ‘yes’ button if the digit was one of the original five digits and the ‘no’ button if the digit was not one of the original digits. The children were instructed to respond as quickly as possible. The dependent measures were accuracy (%) of the original and new stimuli, reaction time (msec) and a sensitivity index measure was derived from the responses.

6.2.3.1.9. Delayed Word Recall

As with immediate word recall, the children were asked to write down as many words as they could remember from the word presentation in 60 seconds. The dependent measures were correctly recalled words (number of and %), number of intrusions and number of errors.

6.2.3.1.10. Delayed Word Recognition

The fifteen original words from the word presentation and fifteen new distractor words were presented on the screen one at the time in random order. The children were instructed to press the ‘yes’ button if the word on the screen was a word from the original list of words and to press the ‘no’ button if the word was not from the original list of words. They were asked to respond as quickly as possible. The dependent measures were accuracy (%) for both original and new stimuli, reaction time (msec) and a sensitivity index measure was derived from the scores.

6.2.3.1.11. Delayed Picture Recognition

The original twenty pictures shown in the picture presentation plus twenty new distractor pictures were presented one at the time on the screen. For each picture the children were instructed to press the ‘yes’ button if the picture was one they had seen during the picture presentation and to press the ‘no’ button if the picture was not one of the original pictures. The dependent measures were accuracy (%) for original and new stimuli, reaction time (msec) and a sensitivity measure (SI) was derived from the scores.

6.2.3.2. Primary outcome measures / factors

The three factors, Speed of Attention, Accuracy of Attention and Secondary Memory are referred to as Power of Attention, Continuity of Attention, and Quality of Episodic Secondary Memory, respectively, in Wesnes et al. (2000; 2003).

6.2.3.2.1. Speed of Attention

This factor was derived by combining the reaction times scores for simple RT, choice RT and digit vigilance. The units are summed milliseconds for the three tasks.

6.2.3.2.2. Speed of Memory

This factor was derived by combining the reaction times scores for numeric working memory, spatial working memory, delayed word recognition and delayed picture recognition. Units are summed milliseconds for the four tasks.

6.2.3.2.3. Accuracy of Attention

The accuracy of attention factor was derived by combining the percentage accuracy across choice RT and digit vigilance with adjustment for false alarms from the latter task. 100 % accuracy across the two tasks generates a maximum score of 100.

6.2.3.2.4. Secondary Memory

This factor was derived by combining the percentage accuracy scores (adjusted for novel and original stimuli) from the delayed word recognition, delayed picture recognition, immediate word recall and delayed word recall tasks (with adjustment to the total % correct for errors and intrusions on the latter two tasks). 100% accuracy across the four tasks generate a maximum score of 400 on this index.

6.2.3.2.5. Working Memory

This factor was derived by combining the percentage accuracy scores from the spatial working memory and numeric working memory tasks. 100% accuracy across the two tasks generates a maximum score of 200 on this index.

6.2.4. Treatments

All children were provided with the high GI cereal *Coco Pops* and the low GI cereal *All Bran* on two consecutive days, with order of presentation counterbalanced across groups. For both cereals children were given a 35g portion accompanied by 125ml semi-skimmed milk. Approximately 15 minutes was allowed for breakfast consumption. It has to be acknowledged that there are differences in energy and macronutrient content as well as GI and palatability between the two cereals. However, as in chapters 4 and 5, the size breakfasts were chosen in order to keep them close to conventional breakfast intake.

Table 6.2: Nutritional characteristics of 35g of All Bran and 35g Coco Pops. The GI value is taken from an international table of glycaemic index (Foster Powell et al., 2002).

Nutrient	Units	All Bran	Coco Pops	No Breakfast
Energy	kcal	98	133	
Protein	g	4.9	1.6	n/a
Fat	g	1.6	0.9	All values=0
Fibre	g	9.5	0.7	
Carbohydrate	g	16.1	29.8	
Sugars	g	2.45	11.9	
Starch	g	10.85	17.85	
Glycaemic Index	GI	42	77	

6.2.5. Procedure

Each child was required to attend a practice day and two active study days that were conducted on consecutive days. Children were tested in groups of six in a quiet area of their school. On arrival on their practice day children were randomly allocated to a treatment group following a Latin Square design counterbalancing the order of treatments across the two active study days. Also, on the practice day, the experimenter ran through the entire test battery with the children and then the children performed the battery on their own. These data were not included in any analyses. It was decided to do the practice session on a separate day for two reasons. The first reason was that, because the battery took a bit longer to complete and involved more explanation and instructions, children would have to come in to school earlier than they normally would to have enough time to run the practice before the baseline measures. This could in itself have a confounding effect on the results as it would have been a difference to the children's normal routine. The second reason was to avoid the possible confounds of having a practice session on one test day and not the others.

The two study days were identical with baseline measures taken at 9:00am after an overnight fast. Breakfast was given at 9.30am and the children were tested again at 9.40am, 10.40am and 11.40am. Each test session lasted approximately 25 minutes.

6.2.6. Statistics

All data was analysed using SPSS.

Change from baseline scores for each outcome factor were analysed by a three-way mixed ANOVA [breakfast (high GI and low GI) x assessment time (9.40am, 10.40am and 11.40am) x age group (6-8yrs and 9-11yrs)]. Breakfast and assessment time were within subjects variables and age group was a between subjects variable.

Where there were significant effects ($p<0.05$) post hoc pairwise comparisons (Bonferroni corrected) were provided. Where there were significant interactions further one-way ANOVAs were carried out. Due to the high number of possible interactions, only significant interactions are reported in the results. Where sphericity assumptions were violated, Huynh-Feldt corrections were provided to reduce Type 1 error. Huynh-Feldt correction was chosen over the alternative Geisser-Greenhouse correction as the latter is a very conservative test which is not recommended as it often overcorrects for violations of sphericity (Huck, 2000).

As in Chapters 4 and 5, results from alternative analysis by ANCOVA are presented in Appendix 10 and it can be seen that this analysis did not alter the results a great deal except for an additional interaction between assessment time and breakfast on working memory.

6.3. Results

Mean scores on baseline and for each time point are presented in Table 6.3 and mean change form baseline scores for each condition by age group at each assessment time are presented in Table 6.4. For plots of raw data for each measure and a list of all F-values see appendices 8 and 9 respectively.

Table 6.3: Mean scores (SD) on baseline and at each assessment time for each breakfast condition by age group.

Measure	Breakfast	Age Group	n	Baseline	9.40 am	10.40 am	11.40 am
Speed of Attention (msec x 3)	Coco Pops	6-8yrs	29	1785.77 (284.21)	2124.64 (551.23)	2317.77 (1096.84)	2569.17 (1440.32)
		9-11yrs	35	1538.37 (226.37)	1737.29 (318.36)	1720.09 (461.80)	1734.41 (451.34)
	All Bran	6-8yrs	29	1788.39 (303.65)	2094.06 (510.42)	2123.76 (545.97)	2208.63 (631.62)
		9-11yrs	35	1511.39 (231.73)	1697.65 (351.20)	1755.60 (566.80)	1772.93 (466.07)
		Total	64				
Accuracy of Attention (% x 2)	Coco Pops	6-8yrs	29	56.77 (17.77)	49.51 (20.27)	50.11 (17.09)	48.49 (17.93)
		9-11yrs	35	67.71 (17.49)	60.06 (25.44)	61.28 (22.91)	48.69 (37.11)
	All Bran	6-8yrs	29	49.06 (28.30)	45.14 (25.55)	47.12 (21.11)	47.62 (17.19)
		9-11yrs	35	68.32 (17.07)	58.51 (27.40)	56.09 (30.47)	56.16 (28.81)
		Total	64				
Speed of Memory (msec x 4)	Coco Pops	6-8yrs	29	4802.56 (1072.15)	5026.25 (1382.44)	4974.74 (1506.85)	4510.99 (1173.93)
		9-11yrs	35	4024.22 (682.03)	3777.75 (805.00)	3794.16 (1168.37)	3708.28 (847.68)
	All Bran	6-8yrs	29	4679.40 (1216.61)	4717.06 (1212.53)	4965.30 (1253.10)	4759.00 (1590.62)
		9-11yrs	35	3946.12 (968.61)	3761.63 (957)	3906.70 (1229.89)	3783.63 (1284.96)
		Total	64				
Secondary Memory (% x 4)	Coco Pops	6-8yrs	29	96.66 (71.83)	59.99 (84.10)	57.46 (82.21)	35.63 (83.66)
		9-11yrs	35	136.23 (48.65)	93.66 (57.60)	86.66 (50.47)	84.99 (52.60)
	All Bran	6-8yrs	29	100.80 (58.57)	76.49 (67.80)	65.39 (56.33)	55.11 (67.34)
		9-11yrs	35	119.33 (63.85)	97.37 (55.45)	91.47 (58.64)	87.99 (51.75)
		Total	64				
Working Memory (% x 2)	Coco Pops	6-8yrs	29	1.04 (0.54)	1.17 (0.62)	0.95 (0.73)	0.96 (0.62)
		9-11yrs	35	1.32 (0.49)	1.32 (0.55)	1.23 (0.62)	1.23 (0.63)
	All Bran	6-8yrs	29	1.06 (0.59)	1.16 (0.56)	0.82 (0.56)	1.12 (0.51)
		9-11yrs	35	1.42 (0.46)	1.38 (0.56)	1.21 (0.53)	1.28 (0.50)
		Total	64				

Table 6.4: Mean change from baseline scores (SD) for each condition and age group across assessment time. Significant effects are indicated in the last column (Ag = Age Group, Br = Breakfast, Ti = Time (assessment time), *p<0.05, **p<0.005, ***p<0.0001)

Measure	Breakfast	Age Group	n	Change from Baseline Scores 9.40 am	10.40 am	11.40 am	Total	Significant effects
Speed of Attention (msec x 3)	Coco Pops	6-8yrs	29	338.87 (407.73)	532.00 (1011.32)	783.40 (1376.13)	371.82 (78.47)	Ag*, Ti**, AgxTi*
		9-11yrs	35	198.92 (213.63)	181.72 (745.89)	196.03 (340.02)		
	All Bran	6-8yrs	29	305.67 (307.27)	335.38 (440.15)	420.24 (486.37)	292.22 (42.45)	
		9-11yrs	35	186.26 (245.00)	244.21 (472.62)	261.54 (355.98)		
		Total	64	257.43 (29.46)	323.33 (60.38)	415.31 (69.91)		
Accuracy of Attention (% x 2)	Coco Pops	6-8yrs	29	-7.26 (15.78)	-6.66 (10.36)	-8.28 (13.53)	-9.22 (1.62)	Ag*, TixBr*
		9-11yrs	35	-7.66 (16.48)	-6.44 (11.92)	-19.02 (26.22)		
	All Bran	6-8yrs	29	-3.91 (18).69	-1.94 (14.09)	-1.44 (18.55)	-6.92 (1.84)	
		9-11yrs	35	-9.81 (15.31)	-12.24 (22.17)	-12.16 (16.83)		
		Total	64	-7.16 (1.58)	-6.82 (1.61)	-10.22 (1.99)		
Speed of Memory (msec x 4)	Coco Pops	6-8yrs	29	223.68 (712.21)	172.17 (1.01)	-291.57 (850.79)	-114.70 (82.93)	Ti*, Ag*
		9-11yrs	35	-246.47 (578.53)	-230.06 (1.08)	-315.93 (731.94)		
	All Bran	6-8yrs	29	37.65 (604.84)	285.90 (899.29)	79.59 (1.13)	2.80 (84.98)	
		9-11yrs	35	-184.48 (720.72)	-39.41 (777.42)	-162.48 (948.72)		
		Total	64	-42.40 (57.06)	47.15 (82.70)	-172.60 (87.74)		
Secondary Memory (% x 4)	Coco Pops	6-8yrs	29	-36.67 (47.54)	-39.65 (42.18)	-61.03 (47.38)	-46.79 (4.35)	Ti**, Br*
		9-11yrs	35	-42.57 (34.20)	-49.57 (40.96)	-51.24 (41.71)		
	All Bran	6-8yrs	29	-24.31 (45.14)	-35.40 (44.70)	-45.69 (51.13)	-30.95 (5.35)	
		9-11yrs	35	-21.95 (48.60)	-27.00 (59.10)	-31.33 (54.17)		
		Total	64	-31.38 (3.58)	-37.91 (4.35)	-47.32 (4.66)		
Working Memory (% x 2)	Coco Pops	6-8yrs	29	0.13 (0.45)	-0.08 (0.53)	-0.08 (0.51)	-0.04 (0.06)	Ti***
		9-11yrs	35	0.01 (0.55)	-0.10 (0.55)	-0.09 (0.73)		
	All Bran	6-8yrs	29	0.10 (0.54)	-0.24 (0.59)	0.06 (0.64)	-0.07 (0.06)	
		9-11yrs	35	-0.03 (0.55)	-0.20 (0.51)	-0.13 (0.43)		
		Total	64	0.05 (0.04)	-0.16 (0.05)	-0.06 (0.06)		

6.3.1. Speed of Attention

The results showed no significant main effect of Breakfast ($F(2,62) = 1.035$; $p = 0.313$). There was, however, a significant main effect of Age Group ($F(2,62) = 5.936$; $p = 0.018$), with better performance for the 9-11 year-olds (211.45) than the 6-8 year-olds (452.59) (Fig. 6.1).

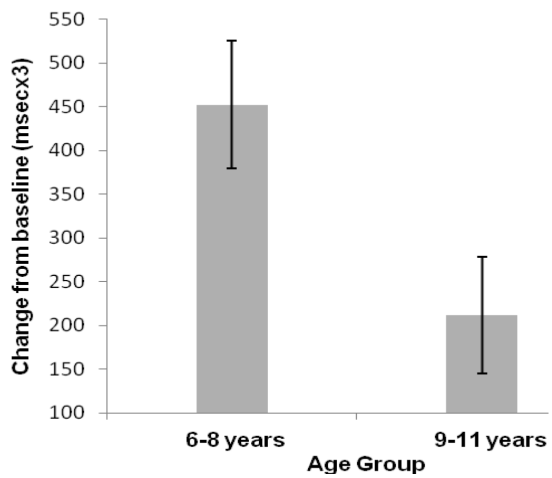


Figure 6.1: Main effect of age on change from baseline scores on the speed of attention factor.

There was also a significant main effect of Assessment Time ($F(1.789, 110.928) = 6.125$; $p = 0.004$, following Huynh-Feldt correction). Pairwise comparisons revealed significant differences between 9.40am and 11.40am ($p <0.05$) with significantly poorer performance at 11.40am (415.31) than at 9.40am (257.43) (Fig. 6.2).

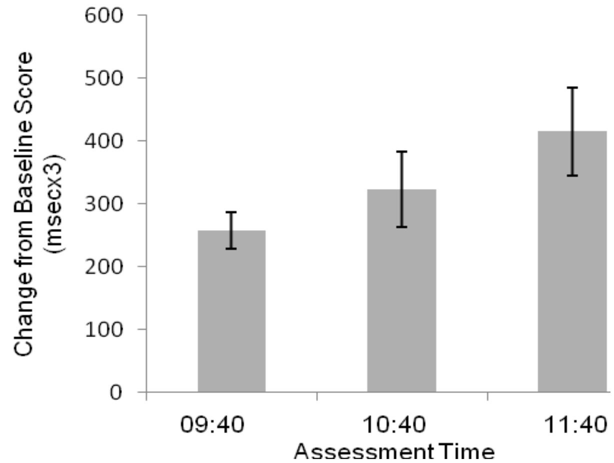


Figure 6.2: Main effect of assessment time on change from baseline scores on the speed of attention factor.

There was also a significant interaction between Assessment Time and Age Group (F(1.789, 110.928) = 3.681; p = 0.028, following Huynh-Feldt correction) (Fig. 6.3). To elucidate the interaction effect one-way ANOVAs were carried out separately for the 6-8 year olds and the 9-11 year olds and the results showed no significant effect of Assessment Time for the 9-11 year-olds (F(2,68) = 0.425; p = 0.656) but a significant effect of Assessment Time for the 6-8 year-olds (F(1.658, 46.425) = 5.162; p = 0.013). Pairwise comparisons revealed a significant difference between 9.40am and 11.40am with better performance at 9.40am (322.27) than at 11.40am (601.82).

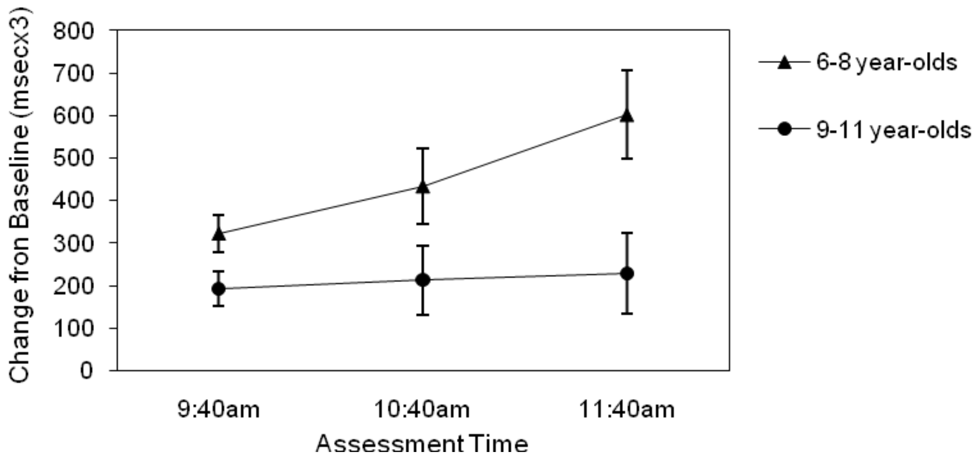


Figure 6.3: Mean change from baseline scores (msec) on Speed of Attention for the 6-8 year-olds and the 9-11 year-olds (please note that a higher change from baseline score indicates poorer performance on this measure).

6.3.2. Accuracy of Attention

Analysis revealed no significant main effects of Breakfast ($F(1,62) = 1.31$; $p = 0.256$) or Assessment Time ($F(2,124) = 2.329$; $p = 0.102$). There was however, a significant main effect of Age Group ($F(1,62) = 4.98$; $p = 0.029$) with better performance for the 6-8 year-olds (-4.92) than the 9-11 year-olds (-11.22).

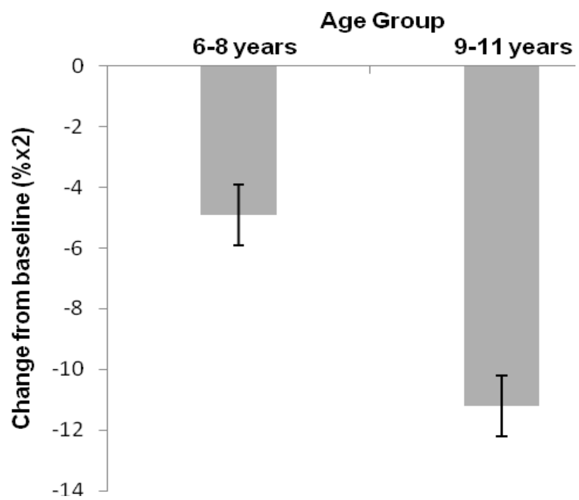


Figure 6.4: Main effect of age on change from baseline scores on the accuracy of attention factor.

The analysis also revealed a significant interaction between Assessment Time and Breakfast ($F(1.903,117.964) = 3.614$; $p = 0.032$, following Huynh-Feldt correction) (Fig. 6.5). Further repeated measures ANOVAs were carried out to check for differences between the High GI (Coco Pops) and Low GI (All Bran) at each Assessment Time point. Analyses revealed no significant differences at 9.40am ($F(1,63) = 0.016$; $p = 0.900$) or 10.40am ($F(1,63) = 0.203$; $p = 0.654$). There was, however, a significant differences between performance following the High and the Low GI breakfasts at 11.40am ($F(1,63) = 5,64$; $p = 0.021$) with better performance after the Low GI (-7.30) than the High GI breakfast (-14.15) suggesting that the interaction between Assessment Time and Breakfast was the result of a sharp decline in performance at 11.40am following the consumption of the High GI cereal.

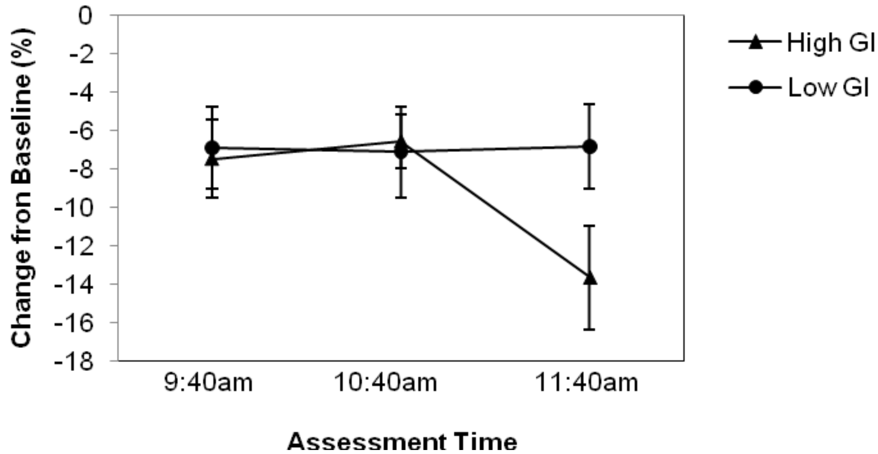


Figure 6.5: Change from baseline scores at each Assessment Time on Accuracy of Attention following High and Low GI breakfasts.

6.3.3. Speed of Memory

Analysis on Speed of Memory showed no significant main effect of Breakfast ($F(1,62) = 1.127$; $p = 0.293$). There was, however, a significant main effect of Assessment Time ($F(2,124) = 4.185$.; $p = 0.017$). Pairwise comparisons showed a significant improvement in performance from 10.40am (47.15) to 11.40am (-172.60) ($p<0.05$) (Fig. 6.6).

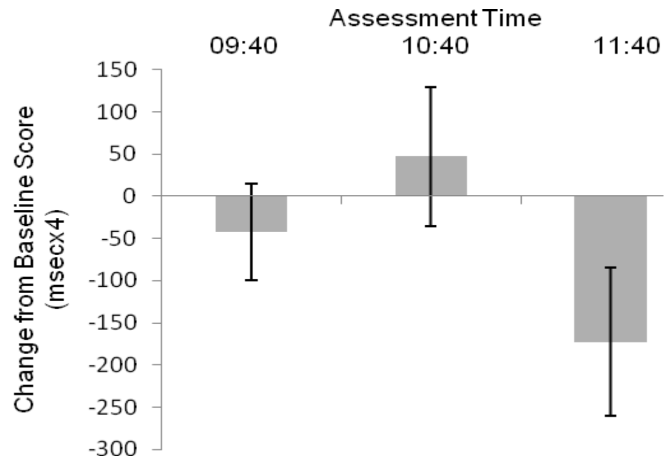


Figure 6.6: Main effect of assessment time on change from baseline scores on the speed of memory factor.

There was also a main effect of Age Group (*F*(2,62) = 4.954; *p* = 0.030) with better performance for the older children (-196.47) than the younger children (84.57) (Fig. 6.7).

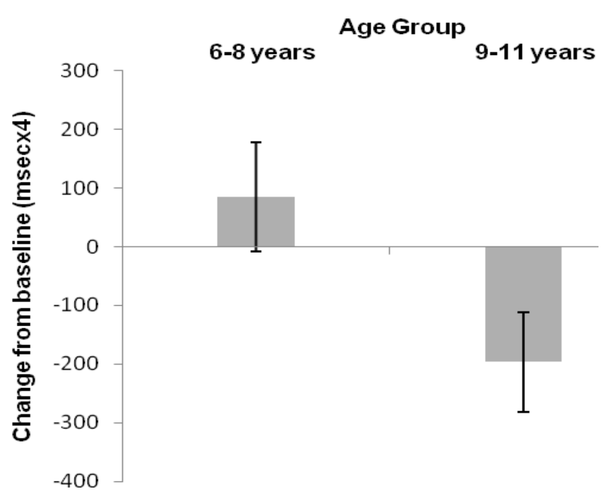


Figure 6.7: Main effect of age on change from baseline scores on the speed of memory factor.

6.3.4. Secondary Memory

Analyses revealed no significant main effect of Age Group (*F*(1,62) = 0.205; *p* = 0.652). There was, however, a significant main effect of Assessment Time (*F*(2,124) = 7.718; *p* = 0.001). Pairwise comparisons revealed a significant difference in performance between 9.40am and 11.40am (*p*<0.01) with better performance at 9.40am (-31.38) than 11.40am (-47.32) (Fig. 6.8).

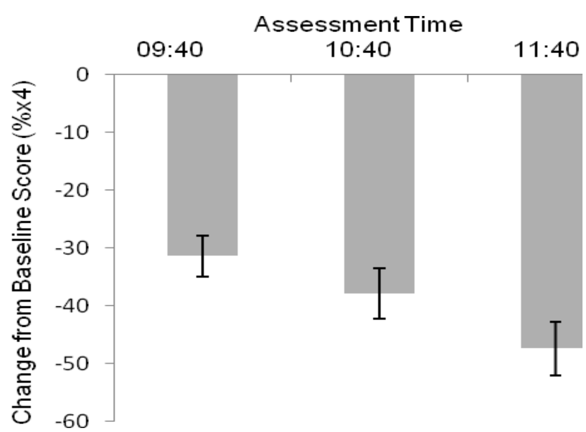


Figure 6.8: Main effect of assessment time on change from baseline scores on the secondary memory factor.

There was also a significant main effect of Breakfast (*F*(1,62) = 5.479; *p* = 0.022) with better performance following All Bran (low GI) (-30.95) than Coco Pops (high GI) (-46.79) (Fig. 6.9).

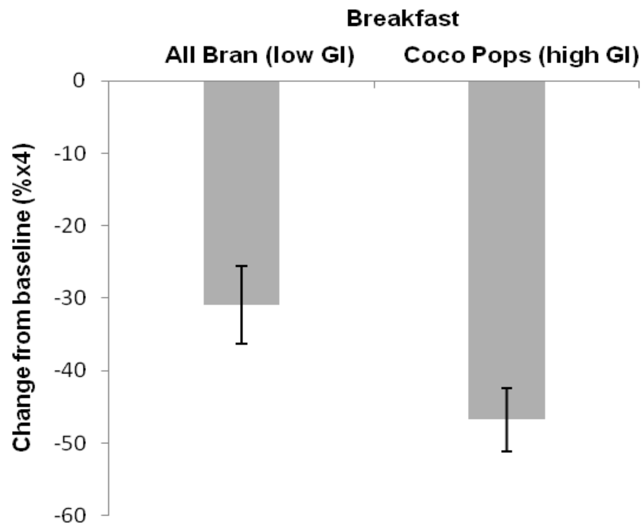


Figure 6.9: Main effect of breakfast on change from baseline scores on the secondary memory factor.

6.3.5. Working Memory

There was no significant effect of Breakfast ($F(1,62) = 0.210$; $p = 0.648$) or Age Group ($F(1,62) = 1.584$; $p = 0.213$). There was, however, a significant main effect of Assessment Time ($F(2,124) = 10.228$; $p = 0.00008$). Pairwise comparisons revealed a significant decline in performance from 9.40am (0.053) to 10.40am (-0.16) ($p<0.001$) (Fig. 6.10).

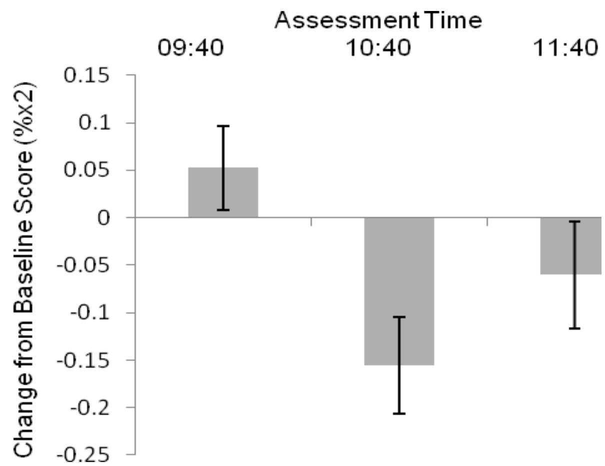


Figure 6.10: Main effect of assessment time on change from baseline scores on the working memory factor.

6.4. Discussion

The current study set out to further investigate the effect of GI of two breakfast cereals on children's attention and memory, as well as look at how these effects differentially target younger and older children. Although not directly assessed, the study also explored cognitive demand of the test battery.

Wesnes et al. (2003) and Muthayya et al. (2007) have suggested that children's performance declines throughout the morning. There were some significant findings in the current study to suggest that performance declines throughout the morning. On Speed of Attention and on Secondary Memory there was a significant decline in performance from 9.40am to 11.40am and on Working Memory there was a significant decline from 9.40am to 10.40am. On Speed of

Memory, on the other hand, there was a significant improvement in performance from 10.40am to 11.40am and although not significant, there was an improvement in performance from 10.40am to 11.40 am on Working Memory. However, apart from the improvement in performance on Speed of Memory and Working Memory, on closer inspection of the means and the tables, it is clear that there was a trend towards a general decline in performance throughout the morning.

Consistent with previous findings by Wesnes et al (2003) and Mahoney et al. (2005), the results from the current study suggest that a low GI breakfast cereal may prevent children's performance from declining throughout the morning on certain measures of attention and memory in children aged 6 to 11 years of age. The results showed that following the consumption of a low GI breakfast cereal compared with a high GI breakfast cereal the decline in performance throughout the morning was significantly less at 11.40am for Accuracy of Attention and a main effect of breakfast showed better performance following the low GI on Secondary Memory. These findings are comparable to Wesnes et al. (2003) who found that after the consumption of either of two breakfast cereals compared to the consumption of both a glucose drink and no breakfast, there was a significantly smaller decline in performance for Secondary Memory. Similarly to Wesnes et al. (2003) the current study also found an effect on Attention. However, for the current study this was manifested in Accuracy of Attention compared with Speed of Attention in Wesnes et al.'s study. The reason for this discrepancy is unknown but may be due to slight differences in task instruction or in participants understanding of how to prioritise speed and accuracy.

Similarities of the current results can also be drawn to those of Mahoney et al. (2005). Although the current study employed a different battery of tests to that of Mahoney et al. (2005), it is noteworthy that GI was found to have differential effects on attention and memory in both studies. Mahoney et al. found that GI had an effect on short-term memory and auditory attention. Extending these findings, the present results suggest that GI has an effect on children's performance on measures reflecting the ability to sustain attention (Accuracy of Attention), and on measures reflecting the ability to store, hold and retrieve information (Secondary Memory).

Mahoney et al. (2005) also found that younger children (6-8 year-olds) might be more susceptible to the effects of GI of breakfast. However, the current findings did not support this notion. The differences in performance between the younger (6-8 years) and the older (9-11 years) children in the current study were not clear as the findings were mixed. On some measures there were main effects of age group with better performance for the older children (Speed of Attention and Speed of Memory); however, on another measure the performance was better for the younger children (Accuracy of Attention). It is, however, interesting to note that the two factors where the 9-11 year-olds outperformed the 6-8 year-olds were factors where the tasks measured reaction time. This corresponds to Rebok et al.'s (1997) results showing improved reaction time from 8 years to 13 years. Furthermore, the age-related findings in the current study did not interact with breakfast and hence the current study found no evidence to support Mahoney et al.'s (2005) finding that the GI of breakfast might affect younger and older children differently. The reason for the differences found in the current study and in that of Mahoney et al. with regards to age is unknown. However, based on previous research that have found age-related changes in both cognitive function (Swanson, 1999; Rebok et al., 1997) and in cerebral glucose utilization Chugani, 1987; 1994), it certainly merits further investigation.

As predicted, the more cognitively demanding test battery employed in the current chapter (CDR) was more sensitive to the subtle changes in cognitive performance induced by the GI of breakfast compared to the test battery employed in previous chapters (CAMBA). Results from the previous chapters did not reveal any significant effects of GI or snack on performance. Previous literature has suggested that glucose intake (or in this case GI) preferentially targets cognitive tasks with a high cognitive demand (Kennedy & Scholey, 2000). This suggestion is indirectly supported by the studies in the current thesis as effects of GI were only detectable when a test battery with a higher cognitive demand was employed. However, although the CDR test battery was deemed to be more cognitively demanding than the CAMBA battery due to the higher number of tests, the higher number of trials within each test and an overall longer completion time, the CDR battery for children is essentially a slightly less demanding version of the adult test battery which raises questions regarding the performance demands of the tasks in the battery. On closer inspection of the CDR battery it has emerged that the difference between the adult version and the children's version of the CDR battery is simply that some tests (tracking, logical reasoning and digit symbol substitution) have been removed from the adult battery. The number of trials, speed etc are still the same for adults and children on the remaining tasks which makes it very likely that some of the tests on the CDR battery used in the current study are too demanding for children. The word lists, for example, contained many long and complicated words that young children would not be expected to understand, read or write (Bogka et al., 2003). During testing it was particularly observed that the children performed at or near floor levels on the word recall tasks as some of the children could not recall any of the words and some children could only remember a few words. Also, the type of words and number of words that a child aged 6 years and a child aged 11 years know are different and such differences in age of acquisition was not controlled for in within the CDR battery. Furthermore, the five primary cognitive factors used in the current study (and in Wesnes et al., 2003) were based on factors derived from factor analysis carried out on adults (Wesnes et al., 2000) and it is possible that these factors are inappropriate for the use with children. For future studies, the CDR battery needs to be made more age appropriate in terms of the tests in the battery and the primary factors also need to be derived from samples of children rather than adults.

In summary, the findings of the current study provide partial support to the notion that a low GI breakfast can have a positive effect on children's cognitive performance throughout the morning, particularly on measures of sustained attention and secondary memory. However, given that the effects of GI were only found on two out of five measures, care must be taken not to generalise the effects to all cognitive functions. Given that Accuracy of Attention and Secondary Memory are constructed of diverse tasks, it is unlikely that the treatments (high and low GI cereal) used in the current study are affecting an underlying shared factor. Hence, it appears that high and low GI meals may differentially affect cognitive functions in children.

CHAPTER 7: General Discussion

7.1. Summary of objectives

The main aim of this thesis was to investigate the influence of the consumption of breakfast and mid-morning snacks on children's cognitive performance (attention and memory) and whether the glycaemic index (GI) of breakfasts has differential effects on performance.

A review of the literature on the effects of snack on children's cognitive performance found that there is a paucity of research on the effects of snack. The few studies that have examined the effects of snack in children (e.g. Busch et al., 2002); Benton & Jarvis, 2007; Muthayya et al., 2007) have provided some mixed findings as to whether snack consumption is beneficial for children's performance and the findings are furthermore clouded by the suggestion that the effects of snack depend on prior breakfast intake. In order to further investigate the effects of snack consumption chapters 2 and 3 compared the effects of apple, banana and no snack on children's attention and memory. Chapter 2 also examined whether the effects of snack are different depending on calorie intake at breakfast.

Reviewing the literature on the effects of breakfast consumption on children's cognitive performance has revealed that there are a number of studies in this area but that the findings are mixed (for reviews see Rampersaud et al., 2005 and Hoyland et al., 2009). Some of the research has found that the provision of breakfast compared to no breakfast enhances cognitive performance (e.g. Connors & Blouin, 1983; Michaud et al., 1991; Vaisman, 1996; Pollitt et al., 1998; Marquez Acosta et al., 2001; Wesnes et al., 2003; Widenhorn-Müller, 2008) and some studies, often the same ones, have found no effects of breakfast (Dickie & Bender, 1982; Cromer et al., 1990; Chandler et al., 1995; Vaisman, 1996; Pollitt et al., 1998). Some studies have additionally found differences in performance following breakfasts with different composition but again with mixed findings (Michaud et al., 1991; Wyon, Abrahamsson, Järtelius & Fletcher, 1997; Mahoney et al., 2005; Benton et al., 2007). Chapters 4, 5, and 6 aimed to investigate the effects of breakfast and more specifically the GI of breakfast on performance in children. Chapters 4 and 5 utilised the same battery as earlier in the thesis and were identical except that chapter 5 additionally aimed to examine whether the effects of breakfast would exert themselves differently in two different age groups (6-8 yrs and 9-11 yrs). Chapter 6 also aimed to investigate breakfast, GI and age but employed a different test battery which was considered to be more cognitively demanding and hence more sensitive to the effects of breakfast.

7.2. General summary of the findings

The results from the series of studies in this thesis did not show any effects of snack and effects of breakfast were only observed on three measures (although one of the interactions revealed no further significant results). Some ambiguous results of age and assessment time were also found, mainly in the breakfast chapters (4, 5, and 6). A summary of the results are shown in Tables 7.1 and 7.2. Table 7.1 shows the results by chapter and Table 7.2 shows the results by variables. The results will be discussed in further detail in the sections below.

Table 7.1: Summary of significant main effects and interactions of snack, breakfast, time and age by chapter. Includes results from pairwise comparisons and further ANOVAs (> indicates better performance on the left, SN=snack, BF=breakfast).

Cognitive Domain	Measure	Ch. 2 (SN)	Ch. 3 (SN)	Ch. 4 (BF)	Ch. 5 (BF)	Ch. 6 (BF)
Attention	SRT				Time: 10.40 > 9.40	
	CRT %					
	CRT msec	*Snack:* trend towards apple/banana > no snack		*Time:* post hoc showed no difference between time points. *Time x Break:* further ANOVAs showed no further significant effects (ch4)		
	Con Att msec					
	Con Att d’					
	Speed Att					*Time:* 9.40 > 11.40 *Age:* 9-11 > 6-8 *Time x Age:* 9.40 > 11.40 for 6-8yrs
	Acc Att					*Age:* 6-8 > 9-11 *Time x Break:* lowGI > highGI @ 11.40
Memory	Corsi				*Time:* 10.40 > 11.40	
	OOO		*Time:* 30>60		*Time:* 10.40 > 9.40	
	Speed Mem					*Time:* 11.40 > 10.40 *Age:* 9-11 > 6-8
	Sec Mem					*Time:* 9.40 > 11.40 *Break:* lowGI > highGI
	WM					*Time:* 9.40 > 10.4

SRT = simple reaction time, CRT % = choice reaction % accuracy, CRT msec = choice reaction time, Con Att msec = continuous attention reaction time, Con Att d’ = continuous attention d’, Speed Att = speed of attention, Acc Att = accuracy of attention, Corsi = corsi blocks, OOO= odd-one-out, Speed Mem = speed of memory, Sec Mem = secondary memory, WM = working memory.

Table 7.2: Summary of significant main effects and interactions by snack, breakfast, time and age. Includes results from pairwise comparisons and further ANOVAs (> indicates better performance on the left).

Cognitive Domain	Measure	Snack	Breakfast	Time	Age	Interactions
Attention	SRT			10.40 > 9.40 (ch5)		
	CRT %					
	CRT msec	*Trend*: apple/banana > no snack (ch2)	See interaction	Main effect but post hoc showed no difference between time points (ch4) See interaction		*Time x Break:* further ANOVAs showed no further significant effects (ch4)
	Con Att msec					
	Con Att d’					
	Speed Att			9.40 > 11.40 (ch6) See interaction	9-11 > 6-8 (ch6) See interaction	*Time x Age:* 9.40 > 11.40 for 6-8 (ch6)
	Acc Att		See interaction	See interaction	6-8 > 9-11 (ch6)	*Time x Break:* lowGI > highGI @ 11.40 (ch6)
Memory	Corsi			10.40 > 11.40 (ch5)		
	OOO			30 > 60 (ch3) 10.40 > 9.40 (ch5)		
	Speed Mem			11.40 > 10.40 (ch6)	9-11 > 6-8 (ch6)	
	Sec Mem		Low GI > High GI (ch6)	9.40 > 11.40 (ch6)		
	WM			9.40 > 10.40 (ch6)		

SRT = simple reaction time, CRT % = choice reaction % accuracy, CRT msec = choice reaction time, Con Att msec = continuous attention reaction time, Con Att d’ = continuous attention d’, Speed Att = speed of attention, Acc Att = accuracy of attention, Corsi = corsi blocks, OOO= odd-one-out, Speed Mem = speed of memory, Sec Mem = secondary memory, WM = working memory.

7.3. Effects of a mid-morning snack

The current thesis did not find any significant effect of a mid-morning snack on any of the cognitive tests: simple reaction time, choice reaction time, corsi blocks, continuous attention task or odd-one-out task. The corsi blocks and odd-one-out tasks both measure spatial working memory. The findings relating to these tasks support Busch et al. (2002) who found that a 25g confectionary snack compared to placebo had no effects on a spatial memory task (map task). There are no previous studies that have employed the simple and choice reaction time tasks and hence, comparisons to other findings are not possible for these results in terms of the specific tasks.

The lack of effects of snack on the continuous attention task (sustained attention) is supportive of the findings of Muthayya et al. (2007). Muthayya et al. tested children on a continuous attention task very similar to the one employed in the CAMBA battery used in the current snack studies where single letters were presented on the screen and the participants had to indicate when two specific letters appeared successively. Muthayya et al. found no effects of the consumption of a snack on children's performance on the continuous attention task. However, contrary to the current results, some research has found effects of snack consumption on children sustained attention. Busch et al. (2002) found that a 25g confectionary snack resulted in a decreased number of false alarms and fewer misses on a continuous attention task similar to the one employed in the CAMBA battery and by Muthayya et al. Benton & Jarvis (2007) did not directly measure sustained attention on a continuous attention task. They measured children's ability to stay focussed on a task (numeracy work) which could be classed as a form of sustained attention. They found that the effect of snack on children's ability to attend to the task was present but only after the children had consumed a small breakfast (<150kcal).

7.3.1. Potential explanations for differences

Given the differences in findings with regards to the benefit of snack consumption on children's cognitive performance, some alternative explanations should be considered as to why there might be such differences.

The differences between the results in the current and previous snack studies could simply be the results of differences in participant samples, individual differences of participants such as fatigue, stress or interpretation of which part of the task to prioritise. An alternative explanation is that it has something do with prior food consumption. In the current study (Chapter 2) children consumed their habitual breakfast before snack consumption and were divided into small (<300kcal) and large (>300kcal) breakfasts. The children in Busch et al.'s study had, on the other hand, fasted since 10pm the night before and were given the snack first thing in the morning like a breakfast. Maybe if a snack is given after a period of fasting it will have an effect on performance but not when it is given as a mid-morning snack following breakfast intake as it may not raise blood sugar sufficiently to affect performance. Considering the results of Benton and Jarvis (2007) who only found effects of snack after a small breakfast which was under 150 kcal and on average only 61 kcal, it is possible that the effects of snack are maybe not only detectable following a fast but that snack might have an effect if prior food intake is relatively low. On the other hand, Muthayya et al. (2007) found effects of snack on tasks not considered here (immediate picture recognition) following a standard 340kcal breakfast which is similar to the small breakfast in the current study. However, Mutahhya et al. only found such effects in low SES children from Bangalore and it is likely that these children are used to a smaller habitual energy supply and hence had lower levels of blood sugar prior to breakfast intake which might have affected the results, as research has shown that food consumption of an evening meal can affect the glycaemic response to a subsequent breakfast (2^{nd} meal effect). Hence, it might be possible that the effects of snack are only detectable when prior blood glucose levels are low, for example after a small breakfast compared to when blood glucose levels are higher like following the intake of large breakfast. This explanation is however further complicated by the fact that Busch et al. actually did find some significant effects on the continuous attention task and together with Muthayya et al.'s mixed findings this might suggest that snack consumption might differentially affect different cognitive domains. This will be further discussed later in the chapter.

Another possibility for the differences in results is differences in the age of the participating children. Welsh et al. (1991) reported that children’s attention becomes more complex and organised at 10 years and that when children reach 12 years of age they have reached adult levels of performance. In the snack studies in the current thesis the children were 12-13 years old. It is possible that the task was too easy for this age group and that the children were performing at ceiling levels so that the additional glucose available from snack consumption is surplus to requirements and unable to facilitate performance. Furthermore, Rebok et al. (1997) found that attention develops fastest between the ages of 8-10 years which is around the age group of the children in Busch et al.’s (9-12) and Benton and Jarvis’ (2007) (9yrs) studies in which they found effects of snack on sustained attention. As Muthayya et al. (2007) did not find any effect on sustained attention in their sample of 7-9 year olds it is possible that these youngest children found the task too difficult and were performing at floor levels. Swanson (1999) examined verbal and spatial memory and found a continuous growth of performance from 6 years of age and Gathercole (1999) reported that improvements on a number of memory components, including working memory, is nearing adult levels at the age of 12 years. The lack of effects both in the current snack studies and in Busch et al. (2002) on spatial memory might again be due to ceiling performance, so that the excess glucose from snack consumption does not facilitate performance.

7.4. Effects of breakfast / GI

The three studies investigating the effects of breakfast on children's attention and memory in the current thesis (Ch. 4, 5 and 6) found three significant effects. There was a significant interaction between assessment time and breakfast on the choice reaction time task (msec) in chapter 4 which employed the CAMBA battery. This interaction, however, did not reveal any further significant effects when further analyses were carried out to elucidate the interaction effect, which might suggest that the effect was a fragile observation. The other two significant results occurred in chapter 6 which used the CDR battery of cognitive tests. Here there was a significant interaction between assessment time and breakfast on the accuracy of attention task which includes accuracy scores from a simple reaction time test and a choice reaction time test. Further analysis revealed better performance after the low GI compared to the high GI at 180 minutes post-breakfast (11.40am). There was also a significant main effect of breakfast on the secondary memory factor which consists of scores from tests of delayed word recognition, picture recognition and immediate and delayed word recall. This main effect showed a better performance following the low GI breakfast than the high GI breakfast.

Interpreting the results of the CDR factors in terms of individual tasks is not possible as the results for the individual tasks on the five factors were not analysed. At the time, it was not considered necessary as the analysis of the factors were carried out to keep the analysis similar to Wesnes et al. (2003). In retrospect it is clear that a better analysis would have been to do additional analysis for each individual test in addition to the factors in order to make comparisons to the CAMBA battery and also to make comparisons with previous research easier. The CDR factors are therefore discussed in a separate paragraph at the end of this section.

The lack of significant effects of breakfast on the spatial memory tests (corsi block and the odd-one-out) supports Benton et al.'s (2007) finding of no effect of breakfast on a spatial memory task (subtest of the British Ability Scale – recall of objects) although their participants were younger children aged 5-7 years. In contrast to these results some research has found effects of breakfast on spatial memory tasks. Vaisman et al. (1996) tested children (boys aged 11-13 years, girls were in grades 5-6 in elementary schools) on the Benton Visual Retention Test and found a beneficial effect of breakfast consumption. Mahoney et al. (2005) also found beneficial effect of breakfast on a map task (spatial memory). In two separate experiments they tested 6-8 year-olds and 9-11 year-olds and found better immediate recall following an oatmeal breakfast compared to no breakfast in both age groups.

In the current three breakfast studies there were no effects of breakfast (GI) on the continuous attention task, neither on the reaction time measure or d' (Ch. 3 and 4). The CDR factor, speed of attention (Ch. 6), included the reaction time scores on a continuous performance task but there was no effect of breakfast on this factor. Direct comparison is, however, difficult to make as there are no results for the individual tasks and the factor is discussed further below. Contrary to the current findings, some studies have found effects of breakfast on continuous attention tasks. Connors & Blouin (1983) found fewer errors and less variability after breakfast compared to no breakfast. Benton et al. (2007) measured the ability to sustain attention using the Shakow paradigm. They found that in children aged 5-7 years performance was better following the low GL breakfast and that there were more lapses of attention following the high GL breakfast. However, corresponding to the lack of effects of breakfast in the current studies neither Cromer et al. (1990) nor Pollitt et al. (1998) found any effects of breakfast on continued (sustained) attention. Similarly, Mahoney et al. (2005) found no effect on breakfast or breakfast composition in either 6-8 year-olds or 9-11 year-olds.

The breakfast studies in the current thesis did not find any effects of breakfast on the simple reaction time task. On the choice reaction time task there was only one significant effect which was an interaction between assessment time and breakfast. However, when further analysed, this failed to produce any further significant results suggesting that this interaction effect is fragile and might reflect minor chance variations.

With the exception of the current thesis (Ch. 6) and Wesnes et al. (2003) there have not been any studies that have used simple and choice reaction time tests with breakfast research in children. However, neither of these two studies reported the results for the individual tests of the CDR test battery. It is, however, interesting to note that the power/speed of attention factor consists of the reaction time scores on a simple reaction time test and a choice reaction time test as well as a continuous performance test. As seen above, there were no effects of breakfast on either the continuous attention task or simple reaction time task in the current thesis but there was an interaction effect between assessment time and breakfast on the choice reaction time test (although fragile). As the calculation of the power/speed of attention factor is simply a summation of the reaction time scores for the three tasks it might be possible that the underlying reason for the observed effect on Wesnes et al.' power of attention factor was an underlying effect on the choice reaction time test. This is, however, only a speculative idea and further analysis on individual tasks would have to be carried out to strengthen such an idea.

The final experimental chapter of this thesis (Ch. 6) employed the CDR battery to test the effects of breakfast composition (GI) and found a beneficial effect of the low GI breakfast compared to the high GI breakfast on the secondary memory factor and on the accuracy of attention factor at 180 minutes post-breakfast (11.40am). The only other study that has used the CDR battery in research on the effects of breakfast in children is Wesnes et al. (2003) who, as mentioned above, found an effect of breakfast on the power of attention factor and also on the secondary memory factor when compared to no breakfast and a glucose drink. Wesnes et al. however, did not examine the difference between their two breakfast cereals whereas the current study specifically examined the differences between the GI of two breakfasts. It is worth noting though that, in both studies, an effect was found on the secondary memory factor which suggests that this factor, or the tests within it, is sensitive enough to detect subtle changes in cognitive performance following breakfast manipulations. For the attention measures however, Wesnes et al. found an effect of breakfast on powered/speed of attention whereas the current study found an effect on accuracy of attention. Both of these factors consist of simple reaction time and choice reaction time tests (plus continuous attention test for power of attention). Although fragile, there was a significant interaction effect (time x breakfast) on the choice reaction time test which might suggest that this test is able to pick up differences in performance. Furthermore, there were no effects of breakfast on either the simple reaction time or continuous attention tasks. As tentatively suggested earlier, it could be that that the observed effects of breakfast/GI on the power of attention (Wesnes et al.) and also on accuracy of attention could be due to the choice reaction time test.

7.4.1. Potential explanations for differences

There are a number of alternative explanations for the mixed findings of a breakfast effect on children's attention and memory both in the previous literature and within the current studies. One factor to consider is differences in participant samples. Considering the studies that have used tasks similar to the tasks employed in the current studies, there are differences in the ages of the samples. Some have examined a younger sample of children whereas others have examined an older sample. Benton et al. (2007) investigated the effects of breakfast in 5-7 year olds children whereas Cromer (1990) examined a sample with a mean age of 14.2 years (no age range was given). Vaisman et al. (1996) examined a sample that consisted of boys aged 11-13 years and girls who were in 5th to 6th grade in elementary school (approximately 9-13 years). Wesnes et al. (2003) investigated the effects in children aged 9-16 years. Both Connor & Blouin (1983) and Pollitt et al. (1998) looked at children aged 9-11 years. In the current studies, chapter 4 looked at 8-10 year olds and chapters 5 and 6 examined 6-11 year olds as did Mahoney et al. (2005). As discussed earlier (Ch. 1), there are differences in glucose metabolism as well as in attention and memory throughout this wide range of ages (5-16 years). This not only makes it difficult to compare the studies but it is also very likely breakfast consumption will have different effects on the younger and older children. Mahoney et al. (2008) split their participants into two age groups, 6-8 year-olds and 9-11 year-olds, and found more effects of breakfast in the younger group (beneficial effect of oatmeal). Chapter 4 in the current thesis examined 8-10 year olds and chapters 5 and 6 looked at children aged 6-11 years. The children in chapters 5 and 6 were split into two groups of 6-8 year-olds and 9-11 year-olds as in Mahoney et al.'s study. Chapter 5 did not find any effects of age whereas there were some age effects in chapter 6. These results will be discussed later in this chapter.

The main change in the series of breakfast studies in the current thesis was the change of assessment battery in chapter 6 to the CDR battery. The CDR battery was assumed to be more cognitively demanding due to a higher number of tasks and longer completion time. Chapter 6 was the only study in the current thesis to find effects of the GI of breakfast (as well as the only one to find age effects). It is possible that this was due to the higher demand of the CDR battery compared to the CAMBA battery. However, this can only be a speculative interpretation as no tests were actually done to determine the difficulty of the tasks within either battery. Scholey et al. (2001) argued that there is a steeper drop in blood glucose in demanding tasks. If the CDR test battery is more demanding it is likely that it has decreased the blood sugar levels at a faster rate which has increased the delivery of glucose to the brain which has in turn has affected cognitive performance.

An explanation for the differences observed between the high and the low GI breakfasts in chapter 6 is that they are due to the different changes in blood glucose induced by the high and low GI. However, it is important to note that the two breakfasts differed on other components as well, such as differences in the amount of energy and also amounts of macronutrients (see Table 4.3) which may have had an impact on the results. It is also possible that the differences between the two breakfasts could have had an impact on the results due to differences in taste and texture. Furthermore, as the studies were carried out at a time when the effects of food and particularly sugar were highlighted in media (e.g. Jamie Oliver's TV shows) it is also possible that the children had certain expectations or knowledge about how each breakfast would affect their performance and consequently caused an expectancy effect. The use of a double-blind methodology would have eliminated such effects but matching the chosen breakfasts on taste, appearance and palatability was not possible.

7.5. Effects of assessment time

Although the current thesis did not specifically set out to investigate the effects of time, a number of significant effects emerged relevant to time. Only one effect of time was found in the snack studies. This showed a better performance at 30 minutes post-snack than 60 minutes post-snack. The rest of the time effects were in the three breakfast studies (Ch. 4, 5 and 6). Three effects showed better performance at 9.40am than 11.40am (0 and 180 min post-breakfast, respectively). These three effects were all observed in chapter 6, one on the secondary memory factor and two on the speed of attention factor although one of these were for the 6-8 year-olds only. On the working memory factor (Ch. 6) there was better performance at 9.40am than at 10.40am and on the corsi blocks test (Ch. 5) performance was better at 10.40am than 11.40am. There were two effects with worse performance at 9.40am than 10.40am, one on simple reaction time and one on the odd-one-out task, both in chapter 5. Finally, worse performance at 10.40am than 11.40 was observed on the speed of memory task in chapter 6.

Few studies on the effect of breakfast or snack report the effects of time where they have tested at more than one time point after breakfast consumption. Wesnes et al. (2003) found a general pattern of a decline in performance after no breakfast across the morning which was attenuated by the consumption of a cereal breakfast. Prior to that, Connors and Blouin (1983) found that performance on a continuous attention task decreased over the morning following both breakfast and no breakfast but that at each time point the performance was worse after no breakfast. The current results of a decrease in performance from 9.40am to 11.40 am (chapter 6) supports the notion that children's performance declines throughout the morning as the performance at 10.40am falls in between the other two times. The notion is also supported by the results from chapter 3 showing a decline from 30 to 60 minutes post-snack. As the other effects were also only significant between two out of three time points, the effects were examined further by examining the 'missing' time point. This revealed some rather muddled patterns as can be seen in the graphs in the respective chapters. It is however, worth noting that, although not necessarily significant, there seems to be a increase in performance from 9.40am to 10.40am and an decrease in performance again from 10.40am to 11.40am for all the time effects in chapter 5 (see Fig. 5.1, 5.2 and 5.3). As discussed in chapter 5, there seems to be something happening that has increased performance at 10.40am. However, it is not known what might have caused this rise in performance and it is only an observation as there were no significant effects between all time points.

7.6. Effects of age

Chapters 5 and 6 in the current thesis looked at the effects of the GI of breakfast in children aged 6-8 years and 9-11 years. Although there was mainly no effect of age, there were three significant effects of age (all in chapter 6). 9-11 year-olds performed better than 6-8 year-olds on the speed of attention and speed of memory factors. The 6-8 year-olds however, performed better on the accuracy of attention factor.

The reason for why the 6-8 year-olds performed worse on the speed tasks (both attention and memory) might be due to developmental differences. Rebok et al. (1997) found that improvements in attention develop fastest between the ages of 8-10 years which suggests that the 9-11 year-olds in the current studies had more advanced attention skills. However, Rebok et al. only investigated age related changes in children aged 8-13 years so it is not known what the rate of development is for children under 8 years compared to over 8 years. Also, this explanation does not account for the current finding that the 6-8 year olds performed better than the 9-11 year-olds on the accuracy of attention task.

Another possibility for the worse performance of the 6-8 year-olds is that the tasks were too difficult for them. However, this still leaves their better performance on accuracy of attention unexplained. An alternative explanation is that the younger children interpreted accuracy as more important than speed and hence performed better on accuracy than speed. Another possibility is that it might be that motor development of the younger children is less advanced and prevents them from responding as quickly as the older children.

It is important to note, however, that there were only a few age effects and these were all on CDR factors which were not broken down into individual tests and as discussed earlier in this thesis it might not be appropriate to use these CDR factors in research with children. However, although the reason for the differences in age is not clear, it warrants further research.

7.7. Differential Effects on Cognitive Functions

When studies examining the effects of breakfast or snack on children's cognitive performance find significant results, care must be taken not to generalise the results to all cognitive functions. Although a number of studies have found positive effects of breakfast and snack consumption on cognitive function in children (Benton & Jarvis, 2007; Busch et al., 2002; Mahoney et al., 2005; Muthayya et al., 2007; Wesnes et al, 2003), many of these studies have only found effects on some of their outcome measures and not others. Furthermore, some studies have found no effects of breakfast or snack at all (Chandler et al., 1995; Dickie & Bender, 1982; López et al., 1993; Pollitt et al., 1982/83). Because effects are found on some cognitive functions and not others, it is possible that the consumption of breakfast and snack preferentially affects different cognitive functions.

Contrary to Busch et al. (2002) who investigated the effects of snack in children, the two snack studies in Chapters 2 and 3 did not reveal any differences in cognitive performance as a consequence of snack consumption. Busch et al. found that children's performance on a vigilance task was significantly better following snack consumption compared to placebo. Benton & Jarvis (2007) found that snack consumption had a positive effect on attention if children had previously consumed a small breakfast (<150kcal) prior to the snack. Muthayya et al. (2007) found an interaction between the caloric size of breakfast, snack consumption and subsequent cognitive performance. However, they found that snack benefitted performance on memory (immediate and delayed) rather than attention and following the intake of a standard breakfast (340kcal) compared to a small breakfast (187kcal). Muthayya et al., however, only found these effects in low SES children.

Chapter 6 in the current thesis was the only chapter to find an effect of breakfast (apart from a fragile interaction effect in chapter 4). These results were, however, observed on different cognitive domains (secondary memory and accuracy of attention). There were, however, no effects on any of the other factors (speed of attention, Speed of memory and working memory). Wesnes et al. (2003) who used the same test battery (CDR) as in chapter 6, found effects of breakfast on secondary memory and speed of memory but no other effects on the other three factors. Chandler et al. (1995) found that performance on a verbal fluency task was significantly improved following breakfast compared to the placebo. However, this effect was only present for the undernourished children and there were no effects on the other measures of visual search, digit span and speed of information processing.

Overall, some studies examining the effects of breakfast or snack on children's cognitive performance have found significant effects on attention (Benton & Jarvis, 2007; Busch et al., 2002) and others have found effects on memory (Muthayya et al., 2007; Vaisman, 1996; Widenhorn-Müller, 2008). Furthermore, some studies, like Chapter 6 in the current thesis, have found effects on both attention and memory (Benton & Stevens, 2008; Mahoney et al., 2005; Wesnes et al., 2003). When looking at the effects of breakfast and snack consumption in both children and adults the results suggest that memory is particularly susceptible to change in response to glucose intake (Hoyland et al., 2008).

From the previous literature on children, and from the studies in the current thesis, it does seem harder to come to a conclusion about which cognitive domains are most susceptible to the cognitive-enhancing effects of raised glucose levels induce by breakfast and snack consumption. Furthermore, the effects may also differentially affect specific areas within attention and memory, such as sustained attention or delayed memory.

In summary, given that effects of mid-morning snack, breakfast or breakfast type (e.g. GI) on children's cognitive performance are usually only found on some of the outcome measures in a study, this might suggest that the effects preferentially target different cognitive domains in children. However, it is also important to acknowledge that such effects might be due to methodological factors such as differences in design, participants, cognitive tasks, procedure, time of day, time of test following intervention and differences in intervention.

7.8. Cognitive Demand

An alternative explanation to the suggestion that breakfast and snack might preferentially target specific cognitive functions is that they preferentially target tasks that have a higher cognitive demand. Previous literature has suggested that more cognitively demanding tasks are more susceptible to the effects of glucose in adults (Fairclough & Houston, 2004; Kennedy & Scholey, 2000). Many studies investigating the cognitive-enhancing effects of glucose have found that the effects are only present during tasks that are more cognitively demanding or require more mental effort. Kennedy & Scholey (2000) for example, reported that a 25g glucose drink, compared to placebo, significantly improved performance on a more difficult mental arithmetic task (Serial Sevens) compared to an easier version of the same task (Serial Threes). Similarly, Scholey et al. (2001) found that glucose, compared to placebo, significantly improved performance on the more demanding Serial Sevens task compared to an easier Word Memory task and a Verbal Fluency task. The suggestion that glucose might preferentially affect tasks with higher cognitive demand is further supported by studies that have found an enhanced effect of glucose on incongruent and not congruent trials of the Stroop test (Benton et al., 1994) and later but not earlier periods during rapid visual processing (Benton et al., 1994; Donohoe & Benton, 1999).

In the current thesis, the only time breakfast (GI) had an effect on performance was in Chapter 6 when the test battery was changed to a battery with higher cognitive demand. One of the arguments used as a reason to why the assessment battery in Chapter 6 (CDR) was more demanding than the assessment battery used in the other chapters (CAMBA) was that the duration of the battery was longer. Benton et al. (1994) found that cognitive-enhancing effect of glucose was only observable in the latter period of a 40 minute cognitive test when fatigue was higher. On the other hand, Fairclough & Houston (2004) examined adults' performance on the Stroop task over 45 minutes and did not find that time-on-task had an effect on performance. In

Chapter 6 the test battery took approximately 25 minutes to complete compared to 15 minutes for the test battery used in the other chapters. This was a somewhat shorter time than the longer tests employed by Benton et al. (1994) and Fairclough & Houston (2004). However, in Chapter 6 in which testing took 25 minutes, significant effects of GI were found for Accuracy of Attention and Secondary Memory with a positive effect of the low GI breakfast. Accuracy of Attention is derived by combining choice reaction time (% correct) and digit vigilance (continuous attention) (% correct with adjustment for false alarms). These two tasks are performed relatively early within the battery of tests and hence, one would not expect that the significant effects are due to time-on-task effects on this measure. On Accuracy of Attention the effect of GI was only significant at 11.40am. This effect fits in with the notion that performance following a low GI food should be better later in the morning than following a high GI food due to the stable and longer lasting blood glucose levels. For Secondary Memory however, there was a main effect of GI. The tests used to derive Secondary Memory were delayed word recognition, delayed picture recognition, immediate word recall and delayed word recall. All of these tasks, except immediate word recall, were performed towards the end of the test battery; delayed word recall, delayed word recognition and delayed picture recognition were in fact the last three tasks of the test battery, respectively. It is possible that the facilitative influence of a low GI breakfast exerts its effects in the latter period of a longer more demanding test battery.

The cognitive demand of the tests in the current thesis was, however, not assessed. It was assumed based on face validity that the CDR battery was more cognitively demanding than the CAMBA battery. As far as the current author is aware, cognitive demand has not been investigated in children. It would have been interesting if Chapter 6 had investigated this further by, for example, asking children to rate the tasks in terms of how difficult they found them. As a change of test battery was not considered a necessity in the earlier chapters of the thesis, the cognitive demand of the CAMBA battery was not rated. Hence, such ratings were considered redundant for the CDR battery as there would have been no ratings to compare it with for the CAMBA battery. It is important to note that the relationship between time-on-task and performance could be due to other factors such as fatigue, boredom or learning effect (Fairclough & Houston, 2004).

7.9. Methodological Considerations and Directions for Future Research

Before drawing conclusions, this section of the discussion will consider methodological issues of the current thesis. Areas for improvement and directions for future research will also be considered.

Where possible, the current series of studies attempted to control for the many potential confounding variables. However, this was not always possible. The children who took part in the current series of studies were provided with breakfasts or snacks which were typical for what children of that age would normally consume, perhaps with the exception of All Bran. It is possible that the breakfast and snacks provided deviated from the children's habitual intake and that this might have affected their cognitive performance as it has been observed that individuals who have different habitual diets differ in aspects of physiology and metabolism (Blundell & Cooling, 2000). Furthermore, the children were clearly not blind to the intervention. Through talking to the children during the studies, it was apparent that many of them were aware of healthy eating and how the consumption of sugar can affect behaviour. Hence, expectancy effects cannot be ruled out in the current series of studies.

Another limitation of the current thesis was that none of the studies included measurements of biomarkers such as levels of blood glucose. Although blood glucose sampling is somewhat a more delicate issue when it comes to testing in children, it may perhaps be important for future studies to include measures of blood glucose levels to construct a clearer picture of the interactions between food and drink consumption, levels of blood glucose, task demand and cognitive performance as well as the underlying mechanism.

Analyses of the effects of breakfast on children's cognitive performance can be complicated by the various school, social and individual factors. One particular factor in all 3 breakfast studies was that there was no real control over whether children had anything to eat or drink throughout the morning. Although the participating children were asked to refrain from eating or drinking anything other than water until testing was finished, they could easily have had a mid-morning snack without the researcher being aware of this. Mid-morning snacks are available in most schools at around 10am. The results from Chapter 5 in the current thesis did not support the notion that there is a decline in children's cognitive performance throughout the morning. On closer inspection of the means and graphs for of the cognitive measures it seemed that there was an improvement in performance from 09.40am to 10.40am and then a decrease in performance from 10.40am to 11.40am on all of the measures (Simple RT, Corsi Blocks, Odd-one-Out and Choice RT) although these improvements/decrements were not all significant. Because food and drink consumption was not monitored throughout the morning, it is possible that the participating children could have consumed a snack at 10am when they were available. If this was the case then this might account for the improvement in performance observed from 9.40am to 10.40am.

Furthermore, in the three breakfast studies in the current thesis (Chapters 4, 5 and 6) parents and children were asked to ensure that the children fasted from 10pm the night before to prevent children from consuming anything other than water that might interfere with the results. However, previous research has suggested that glycaemic response to an evening meal can have an effect on the glycaemic response to a subsequent breakfast (Nilsson et al., 2008; Wolever, Jenkins, Ocana, Rao & Collier, 1988). It is possible that this might also have an effect on cognitive performance. The series of studies in the current thesis did not control for possible effects induced by an evening meal. Future research examining the effects of breakfast on cognitive performance in children should perhaps control for such possible effects. This could be done by providing participants with identical evening meals on the day before testing. Alternatively, participants could be provided with different meals such as high and a low GI evening meal and observe the effects on cognitive performance following high and low GI breakfasts. However, when providing participants with specific meals there is the possibility that they might respond in certain ways because the meals provided are different from their habitual diet.

The results in Chapter 6 which show a beneficial effect of GI on performance have been interpreted as the product of differing GIs between the two breakfasts. However, as discussed earlier, it is important to note that there were compositional differences other than GI between the two cereals. Due to the differing amounts of energy and macronutrients of All Bran and Coco Pops it is possible that the observed results in the present study could be due to compositional factors other than GI.

The lack of effects of breakfast and snack in the current thesis, with the exception of a couple of significant effects in chapter 6, could be due to small sample sizes. As the studies (maybe with exception of chapter 6) had very low cell occupancy it is very likely that they were underpowered and unable to detect subtle differences in performance. Power analyses were not conducted in this thesis which in retrospect could have been useful. With such small sample sizes and underpowered nature of the studies, it is likely that type II errors may have been made throughout the thesis and subtle effects may have been overlooked.

7.10. Conclusions

The current series of studies extends previous literature investigating the effects of breakfast and snacks on children's attention and memory. Overall, the findings add to the mixed findings in the literature. Chapters 2, 3, 4 and 5 did not find any significant effects of snack, breakfast or GI. Although this contradicts many studies that have found effects of such factors on children's cognitive performance (Bush et al., 2002; Benton & Jarvis, 2007; Benton & Stevens, 2008; Mahoney et al., 2005; 2007; Muthayya et al., 2007; Vaisman, 1996; Wesnes et al., 2003; Widenhorn-Müller, 2008) the results partially support the same studies as they tend not to find significant results on all cognitive measures. Such mixed findings may suggest that the cognitive-enhancing effects of breakfast and snack preferentially targets specific cognitive functions. This notion is supported by the findings in Chapter 6 where the results showed a beneficial effect of a low GI breakfast on measures of Accuracy of Attention and Secondary Memory but not on Speed of Attention, Speed of Memory or Working Memory. An alternative explanation postulated for the significant results in Chapter 6 is that the effects of GI were detected because the cognitive test battery had higher cognitive demand. Unfortunately no appropriate measures were taken to determine whether the participating children considered this test battery to be more cognitively demanding, so such an explanation for the current results can only be speculative.

Although there was a lack of significant results in current thesis there were a few significant effects of breakfast and also some effects of age and assessment time. In line with the National Curriculum, children's academic competencies are assessed at 7, 11 and 14 years which have important consequences for the children's further education (Gathercole & Pickering, 2000). If school achievements are of vital importance at this early stage and children's performance can be enhanced through their diet, then research into the effects of breakfast and snack most certainly warrants further attention.

APPENDICES

Appendix 1: Letter to schools

Appendix 1.1: Example letter to schools for snack studies (Ch 2 & 3)

Date

«Head_Teacher»
«Name_of_School»
«Address1», «Address_2», «Address_3»

(0191) 243 7244

Dear «Head_Teacher»,

We are carrying out a project funded by Northumbria University, to investigate the effects of a mid-morning snack on children's school performance. It is well known that children who eat breakfast perform better at school than those who skip breakfast. However, children’s performance still tends to decline throughout the morning. The aim of our current study is, therefore, to examine whether this decline in performance can be reduced by providing children aged 10 to 13 years with a mid-morning snack.

To help us understand how a mid-morning snack can positively affect children’s ability to learn, we would be delighted if your school would participate in this project.

We are currently recruiting children from primary and middle schools in the North East to help us with this research project. Participating children take part on one morning only and will be finished by lunch. The children will be given Apple or Banana or No Snack and they will complete a series of simple and fun computerised tasks. The children who receive no snack will be provided with apples and bananas immediately after testing is finished and they can drink water throughout the morning. For analysis purposes only, the children’s height and weight will be measured as well. The snack will be given to the children in school and suitably qualified and trained staff will administer the computerised tasks, over three brief (approx. 15 minutes) sessions each morning, twice before consumption of the snack and once after the snack. The children will be tested in groups of twelve maximum. On the day of testing we request that the children have their normal breakfast between 7-8am. We will make every effort to keep any disruption to classroom routine to a minimum and we will cover all associated costs.

For your information, we have enclosed a copy of the parental consent form and information for participants. The project has been ethically approved and all researchers have clearance from the UK Criminals Records Bureau.

Please return the attached school consent form in the SAE to indicate your interest in taking part. If you indicate that you are interested in taking part, a member of the research team will contact you in the near future with a view to arranging a meeting in order to discuss the project further. Meanwhile, please feel free to contact us if you have any queries about this research.

Yours Faithfully,

Miss Jeanet Ingwersen
(0191) 243 7244
jeanet.ingwersen@unn.ac.uk

Dr. Greta Defeyter
(0191) 227 3291
greta.defeyter@unn.ac.uk

<u>Research Project: The Effect of a Mid-Morning Snack on Children's Attention and Memory</u>

Researchers: Miss Jeanet Ingwersen and Dr. Greta Defeyter

School Consent form for «Name_of_School» School

I have read and understood all the information provided and I hereby **<u>give / do not give *</u>** consent for the above study to take place at the above named school.

***(please delete as applicable)**

Name:……………………………………………………………………………..………...……..
(please print)

Title:…………….……………………………...……………………………………………..…..…
(please print)

Signed:…………………………………………………Date:…………………………..

Please return this form in the enclosed SAE. If you have any queries please contact:

Miss Jeanet Ingwersen
Division of Psychology
Northumbria University
Newcastle-upon-Tyne
NE1 8ST

(0191) 243 7244
jeanet.ingwersen@unn.ac.uk

Appendix 1.2: Example letter to schools for BF studies (Ch 4, 5 & 6)

Date

«Head_Teacher»
«Name_of_School»
«Address1», «Address_2», «Address_3»

(0191) 243 7244

Dear «Head_Teacher»,

We are carrying out a project funded by Northumbria University, to investigate the effects of breakfast on children's school performance. Children who eat breakfast make fewer errors throughout the morning and have greater concentration and better performance during lessons than children who skip breakfast. Also, children who skip breakfast tend to eat more at lunch and feel sluggish during the afternoon. Breakfast consumption is very important for primary school children because critical learning skills are developed at this age and these skills are fundamental to further learning. However, good concentration and learning are more than the result of just eating breakfast. They are the result of what particular kind of breakfast is consumed. So the aim of our project is to look at how different types of breakfast effects children's learning in children aged 7 to 11 years.

To help us understand how breakfast can positively affect children's ability to learn, we would be delighted if your school would participate in this project.

We are currently recruiting children from primary and middle schools in the North East to help us with this research project. Participating children take part on one morning and will be finished by 12 noon. The children will be given Coco Pops *or* All Bran *or* no breakfast and they will complete a series of simple and fun computerised tasks. For analysis purposes only, the children's height and weight will be measured as well. Breakfast will be given to the children in school and suitably qualified and trained staff will administer the computerised tasks, over four brief (approx. 15 minutes) sessions each morning, once before breakfast and three times after breakfast. The children will be tested in groups of twelve maximum. On the day of testing we request that the children do not have any breakfast before school and that he or she only drinks water (all children will be provided with apples and bananas immediately after testing is finished and they can drink water throughout the morning). We will make every effort to keep any disruption to classroom routine to a minimum and we will cover all associated costs.

For your information, we have enclosed a copy of the parental consent form and information for participants. The project has been ethically approved and all researchers have clearance from the UK Criminals Records Bureau.

Please return the attached school consent form in the SAE to indicate your interest in taking part. If you indicate that you are interested in taking part, a member of the research team will contact you in the near future with a view to arranging a meeting in order to discuss the project further. Meanwhile, please feel free to contact us if you have any queries about this research.

Yours Faithfully,

Miss Jeanet Ingwersen	Dr. Greta Defeyter
(0191) 243 7244	(0191) 227 3291
jeanet.ingwersen@unn.ac.uk	greta.defeyter@unn.ac.uk

Research Project: The Effect of Breakfast on Children's Attention and Memory

Researchers: Miss Jeanet Ingwersen and Dr. Greta Defeyter

School Consent form for «Name_of_School» Primary School

I have read and understood all the information provided and I hereby **give / do not give *** consent for the above study to take place at the above named school.

***(please delete as applicable)**

Name:……………………………………………………………………………..………...……….
(please print)

Title:……………..……………………………...……………………………………………..….……
(please print)

Signed:……………………………………………………Date:…………………………..

Please return this form in the enclosed SAE. If you have any queries please contact:

Miss Jeanet Ingwersen
Division of Psychology
Northumbria University
Newcastle-upon-Tyne
NE1 8ST

(0191) 243 7244
jeanet.ingwersen@unn.ac.uk

Appendix 1.3: Letter to schools for breakfast survey (Ch 4 – pilot)

Date

<name of head teacher>
<name of school>
<address 1>, <address 2>, <address 3>

Dear <name of head teacher>,

Childhood nutrition has recently become a national interest, partly because of concerns over unhealthy diets and obesity. In light of this we are developing a programme of research investigating the relationship between breakfast and children's cognitive performance, such as memory and attention, within schools.

In order to get an idea of what children generally have for breakfast we are undertaking a survey in a number of schools in the Newcastle and County Durham areas. The survey is a brief questionnaire for parents of children aged 7, 9 and 11 and requests information about their children's general breakfast habits. We would be obliged if you could please distribute the attached questionnaire to parents of children aged 7, 9 and 11. To ensure the questionnaires are confidential we have requested that parents return the form in a sealed envelope (envelope provided) to their child's teacher by <date> and have enclosed a pre-paid and addressed envelope for you to return the forms to us by <date>.

The survey is being conducted by a team of experienced researchers and is led by Dr. Greta Defeyter. No personal details other than children's age is required. The information provided will allow us to examine the breakfast habits of seven to eleven year-old children. We plan to investigate the effects of *typical* breakfasts on children's performance and it is therefore imperative that we obtain recent data regarding children's actual breakfast eating habits. All collected data will be stored in a secure cabinet within the Division of Psychology. When the survey is complete a summary of the findings will be sent to all participating schools.

We sincerely hope that your school will participate in this important survey. If you are interested in taking part in any of our further studies looking into the relationship between diet and school performance, please contact Miss Jeanet Ingwersen at any time. If you wish, a member of the research team will be happy to visit you in person to discuss the research with you in more detail. Meanwhile, if you have any queries please do not hesitate to contact us.

Yours Faithfully,

Miss Jeanet Ingwersen
(0191) 243 7253
jeanet.ingwersen@unn.ac.uk

Dr. Greta Defeyter
(0191) 227 3291
greta.defeyter@unn.ac.uk

Appendix 2: Information for participants

Appendix 2.1: Example info for part. for snack studies (Ch 2 & 3)

Research Project:
Does a mid-morning snack have an effect on children's cognitive performance?

Information for Participants & Parents/Guardians

What is the project about?
The project looks at how different types of snacks affect performance on simple memory and attention tasks in children.

What will I be asked to do?
The study will take place on one morning at your school. You will be asked to have your breakfast between 7am and 8am on the morning of the testing and asked to keep a record of what you have had.

On the test day, once you arrive at school in the morning you will be asked to carry out some simple and fun tasks on the computer which will last about 15 minutes. You will then be tested again on the same tasks around 10.30 am and straight afterwards you will receive an apple, a banana **or** no snack (if you receive no snack you will receive an apple or banana once the testing has finished). Approximately one hour later you will be asked to complete the tasks again for one final time. All testing will be finished before lunch.

Are there any reasons I should not take part?
If you take part in this project you will have to eat either a banana or an apple which will be provided fresh on the day of testing. If you **dislike** either of the fruits or have **allergies** to them please do not take part.

Who will have access to the information gathered?
All information will be treated with strict confidence and only the main researcher and project supervisor will have access to the information you give us. No information which can lead to the identification of any child will be revealed in any reports, or to any other people.

If I decide to take part but decide later I want to withdraw?
You can pull out from the study any time you like. If you wish to pull out after testing is finished, pleased contact Jeanet Ingwersen on 0191 243 7244 or jeanet.ingwersen@unn.ac.uk

Will I receive feedback?
We are unable to provide participants with individual feedback. However, at the end of the project a summary of the research will be sent to your school.

Thank you for your interest.

Miss Jeanet Ingwersen
Researcher
jeanet.ingwersen@unn.ac.uk

Dr. Greta Defeyter
Project Supervisor
greta.defeyter@unn.ac.uk

Appendix 2.2: Example info for part. for BF studies (Ch 4, 5 & 6)

Information for pupils/parents/guardians.

Title of research project: Do breakfast cereals high and low in glycemic index have different effects on children's attention and memory?

What is the project about?
Nutritionists around the world consider breakfast to be the most important meal of the day. It provides children with nutrients and energy, making a difference to school and work related performance.

The aim of the study is to investigate whether breakfast cereals which are either high or low in glycemic index have an effect on children's attention and memory. Previous research has identified that eating a breakfast cereal low in glycemic index can improve memory, problem solving, and alertness; which help with overall school performance. After consumption of low glycemic index breakfast children have reported that they feel fuller and more satisfied than those children consuming a high glycemic index breakfast..

What will your child be asked to do?
Taking part in this study will involve your child eating a breakfast cereal on the day of testing. They will either receive a cereal low in glycemic index (All Bran) or high in glycemic index (Coco Pops). The cereals will be administered by the researchers in your child's school. Following the breakfast, your child will be asked to complete a series of simple tests assessing memory and attention. These tests are basic and will last approximately 15 minutes. On one of these days, your child will receive no breakfast but will be given a choice of a banana or apple immediately after testing. No one will have access to the results of the tests except the researchers and they won't be able to identify your child as all children will remain anonymous throughout the process. Your child will not be compared to other children. In addition we ask for you to sign a consent form if you would like your child to take part.

Are there any reasons why your child shouldn't take part?
If you take part in this project you will have to eat two types of breakfast (Coco Pops and All Bran). If you **dislike** any of these foods, or if you are **diabetic** or if you are **allergic** or **intolerant** to any of the ingredients listed below, including the optional foods banana and apple, then you should **not** take part. Please make sure that you are not allergic or intolerant to any of these ingredients.

Please carefully check the ingredients below before making your decision.

Cocopops:

Ingredients	Dietary information
Rice, sugar, chocolate (4.5%), cocoa powder, calcium carbonate, salt, malt flavouring, flavouring, niacin, iron, vitamin B6, riboflavin (B2), thiamin (B1), folic acid, vitamin B12.	Suitable for coeliacs (gluten free)* Vegetarian Vegan Kosher certified Halal certified
* Free from wheat gluten, but will contain traces of hordein (barley protein) from the malt flavouring/extract ingredient. This product is included in the Coeliac Society's list of foods suitable for inclusion in a gluten free diet.	

Nutrition Information (typical values per 100g)					
Energy		Fibre (g)	2	Niacin (mg)	15
- kj	1600	Sodium (g)	0.5	Vitamin B6 (mg)	1.7
- kcal	380	Vitamins		Folic Acid (mcg)	167
Protein (g)	4.5	Vitamin A (mg)	-	Vitamin B12 (mcg)	0.85
Carbohydrates	85	Vitamin D (mcg)	-	Minerals (mg)	
- sugars (g)	39	Vitamin E (mg)	-	Iron	7.9
- starch (g)	46	Vitamin C (mg)	-	Zinc	-
Fat (g)	2.5	Thiamin B1 (mg)	1.2	Calcium	453
- saturates (g)	1	Riboflavin B2 (mg)	1.3	Magnesium	-

All-Bran:

Ingredients	Dietary information
Wheat bran (85%), sugar, malt flavouring, glucose syrup, salt, niacin, iron, vitamin B6, riboflavin (B2), thiamin (B1), folic acid, vitamin D, vitamin B12.	Vegetarian Kosher certified Halal certified

Nutrition Information (typical values per 100g)					
Energy		Fibre (g)	27	Niacin (mg)	11.3
- kj	1200	Sodium (g)	0.85	Vitamin B6 (mg)	1.3
- kcal	280	Vitamins		Folic Acid (mcg)	250
Protein (g)	14	Vitamin A (mg)	-	Vitamin B12 (mcg)	0.65
Carbohydrates	46	Vitamin D (mcg)	3.1	Minerals (mg)	
- sugars (g)	16	Vitamin E (mg)	-	Iron	8.8
- starch (g)	30	Vitamin C (mg)	-	Zinc	6
Fat (g)	4.5	Thiamin B1 (mg)	0.9	Calcium	-
- saturates (g)	0.7	Riboflavin B2 (mg)	1	Magnesium	220

Semi-Skimmed Milk:

Nutrition Information (typical values per 100ml)					
Energy		Vitamins		Calcium (mg)	124
- kj	201	Vitamin D (mcg)	Trac	Magnesium (mg)	11
- kcal	47	Vitamin E (mg)	e	Folate (mcg)	9
Protein (g)	3.6	Vitamin C (mg)	0.04	Pantothenate (mg)	0.7
Carbohydrates	4.8	Thiamin B1 (mg)	2	Biotin (mcg)	3.1
- sugars (g)	4.8	Riboflavin B2 (mg)	0.03	Retinol (mcg)	20
- starch (g)	-	Niacin (mg)	0.25	Carotene (mcg)	9
Fat (g)	1.8	Niacin from	0.1	Potassium (mg)	161
- saturates (g)	1.1	Tryptophan (mg)		Phosphorus (mg)	97
-	0.4	Vitamin B6 (mg)	0.6	Copper (mg)	Trace
monounsaturates	Trace	Vitamin B12 (mcg)	0.06	Chloride (mg)	90
- polyunsaturates	0.1	Minerals	0.9	Manganese (mg)	Trace
- trans fatty acids	-	Iron (mg)		Selenium (mcg)	1.1
Fibre (g)	44	Zinc (mg)	0.02	Iodine (mcg)	31
Sodium (mg)			0.4		
* Contains Lactose					

Who will have access to the information obtained?

Only the principle members of the research team will have access to the data that your child will provide, and it will be treated with the strictest of confidence. Your child's name will not appear on any tests they complete. Instead, they will be identified by a code number, which will be assigned at the outset of the project by the research team. Signed consent forms will be kept separate from all other information at all times to ensure anonymity throughout.

Will your child receive feedback?
No individual feedback will be provided as your child will be taking part anonymously, but a summary of the overall findings will be available from your child's school. You may also request a summary of the overall findings to be sent to you by mail or email.

What if your child agrees to take part, but later decides that they don't wish to continue?
Your child is free to withdraw from the project at any point they wish to do so. If they decide to withdraw after they have completed the tests of memory and attention, inform Jeanet Ingwersen, citing your child's identification code and their data will be withdrawn.

Many thanks for your interest.

Research Team

Jeanet Ingwersen, PhD Psychology student, Northumbria University.

Dr. Greta Defeyter, Research Supervisor, Northumbria University.

If you wish to contact the researchers at any time, Dr. Greta Defeyter can be reached at the University of Northumbria on (0191) 227 3291 or via email on: greta.defeyter@unn.ac.uk

Appendix 3: Consent form

Appendix 3.1: Example consent form for snack studies (Ch 2 & 3)

<Date>

Dear Parent or Guardian,

Your child's school has kindly shown an interest in our research project and we would be grateful if you would read the following information outlining the project's aim, thanking you in advance for your co-operation.

The project is looking at the effects of a mid-morning snack on children's learning. It is well known that children who eat a balanced breakfast perform better at school than those who skip breakfast. However, throughout the morning children's performance tend to decline. Therefore, the aim of the current study is to see whether this decline in performance can be prevented by providing the children with a mid-morning snack.

To help us understand how a mid-morning snack can positively affect your child's ability to learn we would be delighted if you would let your child participate in this study.

The project will involve your child taking part on one morning and will take place within your child's school. Your child will either receive an apple, a banana or no snack and the children will be allowed to drink water throughout the morning. We request that your child has their normal breakfast between 7am and 8am in the morning on the day of testing if this is possible, and that they keep a record of what they have. When your child arrives at school they will be asked to perform a few simple and fun computerised attention and memory tasks, twice before the snack is given and once after the snack. Each test session takes approximately 15 minutes. The children will be tested in small groups and suitably qualified and trained staff will administer the tests.

Participation is voluntary and children who do not wish to participate can withdraw at any time during the project. All information gathered will be strictly confidential, and no information that could lead to identification of any individual will be disclosed in any reports, or to any other party.

Please read the enclosed information for participants and parents carefully. If your child is aged between 12 and 13 years and would like to take part, then please sign the consent slip below and return it to your school as soon as possible.

Yours Faithfully,

Miss Jeanet Ingwersen
Researcher
jeanet.ingwersen@unn.ac.uk

Dr. Greta Defeyter
Project Supervisor
greta.defeyter@unn.ac.uk

Confidential Code (admin use only)……………………..……

<u>The Effect of a Mid-morning Snack on Children's Attention and Memory</u>

Consent form for research project taking place at <Name of School>.

Researchers: Miss Jeanet Ingwersen and Dr. Greta Defeyter

I have read and understood the information for parents relating to the above study and I hereby give consent for my child to take part in the study.

I understand that my child's data will be held anonymously, treated with the strictest of confidence and that they may withdraw from the project at any time.

Child's name:………………………………………………………………………………….
(please print)

Child's date of birth:……………..…………………………………………………………….

Male/Female:………………………………… Child's class:…………………...…………

Parent/Guardian's name:……………………………………………………………………
(please print)

Signed:……………………………………………………Date:…………………………..

Please return this form to your child's teacher as soon as possible.

Appendix 3.2: Example consent form for BF studies (Ch 4, 5 & 6)

Date

(0191) 243 7244

Dear Parent or Guardian,

We are writing to you to describe a project which we will take place at your child's school on the <dates>, with the consent of the Head Teacher <Head Teacher Name>.

The project is looking at the effects of breakfast on children's school performance. Children who eat breakfast make fewer errors throughout the morning and have greater concentration and better performance during lessons than children who skip breakfast. Also, children who skip breakfast tend to eat more at lunch and feel sluggish during the afternoon. Breakfast consumption is very important for primary school children because critical learning skills are developed at this age and these skills are fundamental to further learning. However, good concentration and learning are more than the result of just eating breakfast. They are the result of what particular kind of breakfast is consumed. So the aim of our project is to look at how different types of breakfast effects children's learning in children aged 7 to 11 years.

To help us understand how breakfast can positively affect your child's ability to learn, we would be delighted if you would let your child to participate in this study.

The project will involve your child taking part on one morning. Participating children will be provided with Coco Pops *or* All Bran *or* no breakfast. The children will be provided with apples and bananas immediately after testing and will be allowed to drink water throughout the morning. On the day of participation we request that your child does not have any breakfast before school and that he or she only drinks water. The breakfasts will be given to the children in school and simple and fun computerised attention and memory tests will be administered before and after the breakfast and all testing will be finished by lunch. The children will be tested in small groups of twelve maximum and suitably qualified and trained staff will administer the tests. For analysis purposes only, we will also measure the children's height and weight.

Participation is voluntary and children who do not wish to participate can withdraw at any time during the project. All information gathered will be strictly confidential, and no information that could lead to the identification of any individual will be disclosed in any reports, or to any other party.

Should you have any questions, please do not hesitate to contact Miss Jeanet Ingwersen at Northumbria University, on 0191 243 7244.

Please read the enclosed information for participants and parents carefully. If you child is aged between 7 and 11 years and would like to take part, then please sign the consent slip below and return the form to your child's teacher as soon as possible.

Yours faithfully,

Miss Jeanet Ingwersen
Researcher Project
Supervisor
jeanet.ingwersen@unn.ac.uk greta.defeyter@unn.ac.uk

Confidential Code *(for admin use only)*:………………..

Research Project: The Effect of Breakfast on Children's Attention and Memory

Consent form for research project taking place at <Name of School>.

Researchers: Miss Jeanet Ingwersen and Dr. Greta Defeyter

I have read and understood the information for parents relating to the above study and I hereby give consent for my child to take part in the study.

I understand that my child's data will be held anonymously, treated with the strictest of confidence and that they may withdraw from the project at any time.

Child's name:……………………………………………………………………………………….
(please print)

Child's date of birth:……………..……………………………………………………………….

Male/Female:…………………………………… Child's class:……………………..……...…………

Parent/Guardian's name:………………………………………………………………...………
(please print)

Signed:…………………………………………………Date:…………………………..

Please return this form to your child's teacher as soon as possible.

Appendix 4: Debrief

Appendix 4.1: Example debrief for snack studies (Ch 2 & 3)

Confidential Code (for admin use only):………………..

Participant and Parent/Guardian Debriefing

Research Project: The Effect of Mid-Morning Snack on Children's Attention and Memory

Thank you for taking part in this project. The aim of the study is to find out whether eating a mid-morning snack can help to improve attention memory over the morning. Unfortunately, we cannot give you any information on your individual performance. However, a summary of the overall findings will be sent to your school when the project is completed.

You are reminded of your right to withdraw from the study at any time. If you choose to do so, please contact Miss Jeanet Ingwersen on 0191 243 7244 or jeanet.ingwersen@unn.ac.uk giving your confidential code (on top of this sheet) and all your data will then be destroyed.

Thank you again for taking part in this study.

Yours faithfully,

Jeanet Ingwersen

Appendix 4.2: Example debrief for BF studies (Ch 4, 5 & 6)

Confidential Code *(for admin use only)*:………………..

Participant and Parent/Guardian Debriefing

Research Project: The Effect of Breakfast on Children's Attention and Memory

Thank you for taking part in this project. The aim of the study is to find out whether eating specific types of breakfasts can help to improve your memory and your ability to learn in class over the morning. Unfortunately, we cannot give you any information on your individual performance. However, a summary of the overall findings will be sent to your school when the project is completed.

You are reminded of your right to withdraw from the study at any time. If you choose to do so, please contact Miss Jeanet Ingwersen on 0191 243 7244 or jeanet.ingwersen@unn.ac.uk giving your confidential code (on top of this sheet) and all your data will then be destroyed.

Thank you again for taking part in this study.

Yours faithfully,

Jeanet Ingwersen

Appendix 5: Breakfast survey questionnaire (Ch 4 – pilot)

Breakfast Survey

A team of researchers at Northumbria University are developing a programme of research investigating the relationship between breakfast and school performance.

In order to get an idea of what children generally have for breakfast we are undertaking a survey in a number of schools in the Newcastle and County Durham areas. We would be grateful if you would please take time to fill in this questionnaire and return it in a sealed envelope (envelope provided) to your child's teacher before <date>. There are no right or wrong answers to these questions; we want to know what children typically eat for breakfast.

Please sign this form at the bottom to show that you give consent for the information you provide to be used in the research. Any information gathered will be strictly confidential, and no information that could lead to the identification of any individual will be disclosed in any reports, or to any other party.

Thank you for your help.

Yours Faithfully,

Miss Jeanet Ingwersen   Dr. Greta Defeyter

Name of School:…………………………………………………………………...

Your child's **date of birth** (if you have more than one child attending the school please list the dates of birth for all of your children attending the school)

1st child: …………………………………….

2nd child: ……………………………………

3rd child: …………………………………….

1)*What* does your child (or children) generally eat for breakfast?

(Please note down everything that your child would normally eat for breakfast, including crisps and chocolate. You do not need to specify the amounts but please specify what kind of cereal, white or brown bread etc.).

1st child:

2nd child:

3rd child:

2) *What* do they drink with their breakfast?

1st child:

2nd child:

3rd child:

3) At *what time* do they eat breakfast?

1st child: ……………………a.m. …………n/a

2nd child: ……………………a.m. …………n/a

3rd child: ……………………a.m. …………n/a

4) *Where* do your children have their breakfast? (e.g. at kitchen table, in front of tv, at school etc.).

1st child:

2nd child:

3rd child:

5) Any other comments? (e.g. does your child not want to eat breakfast etc.).

I have read and understood the information provided to me and I hereby give consent for the information I have provided to be used in the research described above.

(Signature)…...……………………………………………………………………………

<u>Please return this form in the envelope provided (sealed) to your child's teacher by <date>.</u>

Appendix 6: Studies Evaluating the Effects of Breakfast on Cognitive Function.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
Benton et al. (2007) UK	10 ♀ 9♂ Mean 6:10 Range 5:11-7:8 Low SES	4-week school breakfast club. Breakfast 0815-0845. Testing 1035-1145.	Three BF with similar energy while differing GL. 1. High GL Cornflakes, semi-skimmed milk, sugar, waffle, maple syrup. 196kcal, GL=17.86 (as consumed). 2. Medium GL Scrambled eggs, bread, jam, low-fat spread, low kcal yoghurt. 168kcal, GL=12.09 (as consumed). 3. Low GL Ham, cheese, burgen bread, low-fat spread. 157kcal, GL=2.85 (asconsumed).	Memory (I&D): Verbal and Spatial object recall (British Ability Scale) Sustained attention: Shakow paradigm (3 and 12 sec warning)	Correlations: GL inversely related to immediate memory. GL improved 2nd test with 12 sec warning) ANOVA: No effect	Differences in BF intake. Differences in macronutrients. Small sample. Unbalanced design. BBC
Connors & Blouin (1983)	Ten 9-11 year-olds.	Repeated measures.	1. BF: milk, cereal, sugar, egg, juice, toast). 2. No BF.	CPT Arithmetic test EEG	CPT: less errors and variability following BF.	

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
USA		Four tests, approx 1 week apart. Each condition was administered twice. 30 min CT battery. CT at 0950, 1100 and 1210.			Arithmetic: better following BF at mid-morning. EEG: cardiac acceleration and amplitude of evoked potentials reduced following BF.	
Cromer et al. (1990) USA	Thirty-four high school children. Mean age 14.2 years. 2 groups: 1. School BF: 11♀, 7♂. Mean IQ 102 2. Control (Low energy): 9♀, 7♂. Mean IQ 108.	Independent groups. Evening meal at 1900. BF at 0700. Blood sample at 2100, 0600, 0800 and 1100. CT at 60 and 240 min.	1. School BF: Doughnut, chocolate milk, orange juice (424kcal, 63.9g CHO, 11.5g protein, 14.1g fat). 2. Control (low energy): Sugar free powdered drink; sugar fere gelatine (12kcal, 1g CHO, 1.6g protein, trace fat).	Screen for IQ: Peabody picture vocabulary Memory: RAVLT Visual perception: MFFT Attention: CPT	Glucose: No difference in BF blood glucose profiles. Cognition: No effect of BF	Monetary incentive. National Institutes of Health
Dickie & Bender (1982)	2 age groups:	Independent groups.	1. BF + snack 2. BF 3. No BF + snack	Letter cancellation test	No effects	Results confounded by lunch intake. Kellogg's

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
Study 1 UK	1. mean age 12.5 years (n=227) 2. Mean age 15.3 years (n=260) Mixed SES	Proportion of sample repeated procedure after one week. CT pre and post lunch.	4. No BF BF: solid food before school Snack: food/drink during break			
Dickie & Bender (1982) Study 2 UK	108 children in 4 boarding schools. Investigation 1: 55 children, mean age 17.0 years. Investigation 2: 53 children, mean age 16.2 years.	Independent groups. Three consecutive days of two weeks. BF at 0745. 20 min CT battery at approx 1100.	1. BF week 1 and BF week 2 2. BF week1 and No BF week 2. BF: usual BF at school (approx 477kcal).	Investigation 1: Visual search (MAST4 and 6) Simple addition Investigation 2: Sentence verification.	No evidence that breakfast omission can affect cognitive performance in either investigation.	No counter balancing. Kellogg’s.
López et al. (1993) Chile	279, mean age 10:3 (145♀, 134♂). Low SES Normal (n=106) Wasted (n=73) Stunted (n=100)	Independent groups. 24 min CT at 60 min.	1. BF: two cakes, 200ml drink (394kcal, 6g protein). 2. No BF	Digit span Problem solving (domino test) Attention test	No effect of BF	Néstle Ministry of Education (Chile)
Ma et al. (1999)	151 grade 3 children	Five consecutive days.	1. High energy BF 2. Low energy BF	Addition Multiplication	No effect of energy intake	

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
China	(approx 7 year-olds).	CT late morning on days 2-5.		Number checking Logic Creativity		
Mahoney et al. (2005) Expt 1 USA	15♀ and 15♂, 9-11years. Mean BMI 21. Middle SES.	Repeated measures. CT once a week for 4 weeks (preferred BF repeated on test 4). CT at 60 min.	1. Oatmeal (43g), skimmed milk (200kcal, 38g CHO, 19g sugar). 2. Readt to eat cereal (36g), skimmed milk (180kcal, 36g CHO, 22g sugar). 3. No BF	Attention: CPT (visual + auditory) Memory: Spatial (map task) I&D Working (digit span) Verbal (story recall) Visual perception: Rey complex figure	Attention (CPT auditory): fewer false alarms after oatmeal. Spatial (map): better immediate after oatmeal. Working (backward digit span): better after oatmeal for girls. Visual perception (Rey): better copy after oatmeal. No other effects.	Monetary incentive.
Mahoney et al. (2005) Expt 2 USA	15♀ and 15♂, 6-8 years. Mean BMI 17.7. Middle SES.	As Mahoney et al. (2005) Expt 1.	As Mahoney et al. (2005) Expt 1	As Mahoney et al. (2005) Expt 1 with modifications for younger participants.	Attention (CPT auditory): more hits and fewer misses after oatmeal than ready to eat. Spatial (map): better immediate after oatmeal than no BF. Working (backward	Monetary incentive.

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
					digit): better after oatmeal for girls. Visual perception (rey) better after ready to eat than no BF for boys. Better after no BF than ready to eat for girls. No other effects.	
Marquez Acosta te al. (2001) Venezuela	Sixty-eight 9-10 year-olds. Private school.	Repeated measures.	1. BF 2. No BF	Attention: Lepez Raven's logical reasoning	Improved logical reasoning after BF.	Analysis not stated.
Michaud et al. (1991) France	319 13-20 year-olds. 169 ♀, mean age 15.9 years 150 ♂, mean age 16.1 years	Repeated measures. Cluster randomisation. Cross-over. BF at home. 10 min CT battery at 1100.	Day 1: normal BF intake Day 14: additional energy intake than usual. Gouped by extra amount consumed: 1. 0-99kcal 2. 100-199kcal 3. 200-299 4. 300-399kcal 5. 400+kccal	Short-term spatial memory Visual word search	Improved memory on day 14. Decreased visual search performance on day 14 No effect of size of BF on memory or visual search	
Pollitt et al. (1982-3)	Thirty-nine 9-11 year-olds,	Repeated measures,	1. BF: waffles, syrup, margarine,	IQ measured with Peabody Picture	Visual perception: fewer errors after	Ford Foundation

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
USA	mean age 10:4 (20♀, 19♂).	counter balanced. Evening meal at 1700. BF at 0800. CT at 180 min.	orange juice, milk (448kcal, 65g CHO, 12g protein, 16g fat). 2. No BF.	Vocabulary. Visual perception: MFFT Attention: HCI (Hagen Central Incidental Task) Short-term memory: Xylophone tapping Digit span	BF on difficult version Attention (HCI): better recall after no BF than BF.	
Pollitt et al. (1998) USA	Thirty-two 9-11 year-olds (23♀, 9♂).	Repeated measures, counter balanced. Evening meal at 1700. BF at 0800. CT at 180 min.	1. BF: 535kcal, 75g CHO, 15g protein, 20g fat. 2. No BF	Visual perception: MFFT Attention: HCI CPT	Visual perception: worse after no BF for lower IQ HCI: better recall after no BF No other effects.	
Vaisman et al. (1996) Israel	569 11-13 year-olds (279♀, 290♂). Mixed SES	Independent groups CT at 120 min (BF at home) or at 30 min (BF at school).	Baseline: BF at home or no BF 14 day intervention: 1. BF at school (2/3 of sample) 2. No BF instruction (1/3 of sample) BF: 30g sugared	Memory: RAVLT (I&D, recognition) Benton Visual Retention test (visuospatial) Wechsler Memory Scale revised –	Baseline: better immediate verbal recall after BF. Post-intervention: RVALT: better learning, best learning, inhibition and recognition	Unbalanced design.

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
			corn flakes, 200 ml milk.	story (logical)	following BF at school compared to BF at home or no BF. Benton test: better after BF at school than at home Wechsler: better after BF at school than home.	
Wesnes, et al. (2003). UK	15 ♀, 9-16yrs, mean 12.3yrs 14♂, 9-16yrs, mean 12.1yrs All similar SES	4-way cross-over on four consecutive days (day prior to testing = intro). 25 min CT battery. CT at 0, 30, 90, 150, 210 min (approx).	1. Shreddies (45g) + semi-skimmed milk (125ml). 38.3g CHO (25.2g complex CHO, 6.9g sucrose, 6.25g lactose). 2. Cheerios (30g) + semi-skimmed milk (125ml). 28.7g CHO (16.0g complex CHO, 6.4g sucrose, 6.25g lactose) 3. Orange flavoured drink (330ml). 38.3g CHO as glucose. 4. No breakfast.	CDR battery: Word recall (I&D) SRT Digit vigilance CRT Spatial WM Word recognition Picture recognition Combined into five factor scores	General decline in performance throughout morning. Cereal BF reduced decline in performance on power of attention and quality of episodic memory. Trends for other factors.	Wide age range - not included in analysis Factor scores derived from adult data No analysis of individual tests

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
Widenhorn-Müller et al. (2008) Germany	104 13-20 year-olds, mean age 17.2 years (50♀, 54♂). 88% regular BF eaters (five or more times per week)	Repeated measure, counter balanced cross-over. 7 day wash out. BF at 0730. CT at 45 min.	1. BF 60g wholewheat bread, 20g butter, 20g nougat spread, 20g strawberry jam, ad libitum water and sweetened peppermint tea (475kcal)	Attention: visual search (d2 test) Memory: Object recall Trail route (spatial) Logos (picture recall) Turkish vocabulary (recognition) Telephone numbers (paired associates) Fact cued recall.	Memory: positive effect of BF in male (presence of order effect) No other significant effects.	Unbalanced breakfast conditions.
Wyon et al. (1997) Sweden and Denmark	195 10 year-olds (suburban)	Independent groups. CT in late morning.	1. Good BF eaten at home: good variety and macronutrient balance. Yoghurt and sour milk product, cereal, sandwiches (cheese or pate), orange juice, milk, tea, hot chocolate (mean 509kcal). 2. Bad BF eaten at home: poor variety, low protein. Sweet	Addition Multiplication Grammatical logic Visual search (Number checking) Reading (speed and comprehension) Word recognition Creativity	Better speed and fewer errors on creativity following good BF	Swedish National Dairy Association.

Appendix 6: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
			drink, bread, jam, sweet bread (mean 200kcal).			

CPT: continuous performance test, CRT: choice reaction time test, CT: cognitive test(s), D: delayed, I: immediate, SRT: simple reaction time test, WM: working memory, RAVLT: Rey auditory verbal learning test, MFFT: matched familiar figures test

Appendix 7: Studies Evaluating the Effects of Snacks on Cognitive Function.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
Benton & Jarvis (2007)	20 children, mean age 9:4 (10♀, 10♂).	Random allocation to two groups of ten. Half consumed snack, half no snack. BF at home Snack at 1045 Observation at 1115-1215	BF arbitrarily divided into three groups: 1. <150kcal (mean: 61.2kcal, 12.6g CHO, 1g fat, 1.1g protein) 2. 151-230kcal (mean: 209.7kcal, 38.3 CHO, 4.8g fat, 6.1g protein) 3. >230kcal (mean: 270.3kcal, 41.2g CHO, 6.1g fat, 9.4g protein) Snack: muesli bar (226kcal, 35g CHO, 1g fat, 2.5g protein)	Observation while carrying out numeracy work: Time on task	No effect of snack when analysed independent of BF More time on task, less fidgety, less distracted after snack following small BF (<150kcal)	Kellogg's
Benton et al. (2001)	150♀, mean age 21:3.	Random allocation. BF at 1000. Snack at 1130. Memory measured at 0930, 1015, 1100, 1145 and 1230. Blood glucose	1. Fasted throughout. 2. No breakfast + snack 3. 10 g corn flakes + no snack 4. 10 g corn flakes + snack 5. 50 g corn flakes + no snack 6. 50 g corn flakes	Memory: word recall (I&D)	Better recall at 1145 after snack Spent longer time to recall after either BF (prior to snack) (interpreted as increased motivation).	Monetary incentive Kellogg's

Appendix 7: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
		measured at regular intervals	+ snack BF 10g cornflakes + 40ml skimmed milk: 51kcal, 10.2gCHO, 2.2g protein, 0.1g fat, 0.3g fibre. BF 50g cornflakes: 253kcal, 51g CHO, 10.8g protein, 0.6g fat, 1.5g fibre. Snack 25g cornflakes: 127kcal, 25.5g CHO, 5.4g protein, 0.3g fat, 0.8g fibre.			
Busch et al. (2002) USA	21♂ Range 9-12 years.	Counter-balanced cross-over. 1 week washout. 45 min CT battery. Snack at approx 0800. CT at 15 min post-snack.	1. Confectionary snack (25g). Predominantly simple CHO 2. Aspartame matched for sweetness.	Memory: Spatial (Map task) Verbal (story recall) Working (digit span) Attention: CPT Visual perception:	Better attention following snack than aspartame. No other effects.	Parents paid for child taking part. Mars Inc.

Appendix 7: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
				Rey Complex Figure		
Dickie & Bender (1982) Study 1 UK	2 age groups: 1. mean age 12.5 years (n=227) 2. Mean age 15.3 years (n=260) Mixed SES	Independent groups. Proportion of sample repeated procedure after one week. CT pre and post lunch.	1. BF + snack 2. BF 3. No BF + snack 4. No BF BF: solid food before school Snack: food/drink during break	Letter cancellation test	No effects	Results confounded by lunch intake. Kellogg's
Mahoney et al. (2007) Expt 1 USA	Thirty-eight undergraduates (18-22 years) Mean BMI 23.02	Random assignment to snack or placebo. One day a week for two weeks. Breakfast provided, then lunch 3 hours later, then testing 3 hours after lunch.	1. Snack: 50g confectionary product (44g CHO, 25g glucose, 32g sucrose, 2g maltose 7.5g higher oligosaccharides) 2. No snack / placebo	Spatial memory (map task) Secondary task (short narratives – free + long-term recall of story line and target words)	Map recall: better long-term recall after snack for correct recall and % blanks. Secondary task: fewer hits and more misses after snack. RT for false alarms better after snack. There were no other significant results.	Monetary incentive

Appendix 7: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
Mahoney et al. (2007) Expt 2 USA	Thirty-eight boys (9-11 years) Mean BMI 18.57 No learning disorders	Random assignment to snack or no snack. One day a week for two weeks. Lunch approx 3hours prior to test session.	1. Snack: 25g confectionary product (22g CHO, 12.5g glucose, 16g sucrose, 1g maltose, 3.75g higher oligosaccharides) 2. No snack / placebo.	Spatial memory and secondary task as in Expt 1 with age appropriate adjustments made for the map task. CPT	Spatial memory: better recall, placement and fewer blanks after snack for both short and long term memory. Secondary task: more hits and fewer misses after snack. Better short term recall after snack. CPT: more hits during interval one after snack. No other significant effects.	Monetary incentive
Muthayya et al. (2007) India	Seventy-three 7-9 year-olds (4 excluded from analysis). Low SES n=34 (19♀, 15♂). High SES n=35 (13♀, 22♂).	Repeated measures, counter balanced. 1 week washout.	Three equi-energetic meals (840kcal): 1. Control: standard BF (340kcal), no snack, standard lunch (500kcal). 2. Small BF (1887kcal), snack (153kcal), standard lunch	Memory: Picture recognition (I&D) Attention: CPT Psychomotor: Finger tapping	Low SES: smaller decline in I and D memory in condition 3.	Unilever, NL

Appendix 7: Continued.

Author, Year, Location	Participant Characteristics	Design	Intervention	Cognitive Measures	Findings	Comments
			(500kcal). 3. Standard BF (340kcal), snack (153kcal), small lunch (347kcal). BF: chapatti and potato curry.			

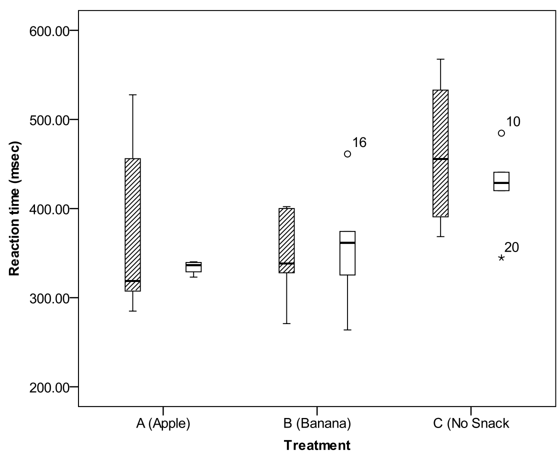
CPT: continuous performance test, CRT: choice reaction time test, CT: cognitive test(s), D: delayed, I: immediate, SRT: simple reaction time test, WM: working memory, RAVLT: Rey auditory verbal learning test, MFFT: matched familiar figures test

Appendix 8: Plots of Raw Data for all Measures

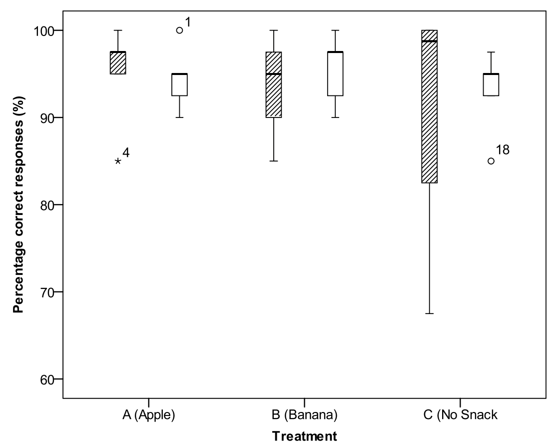
Chapter 2: [snack (apple, banana, no snack) x breakfast (small, large)]. Cognitive tests at 90 min post-snack.

small breakfast (<300kcal)
large breakfast (≥300kcal)

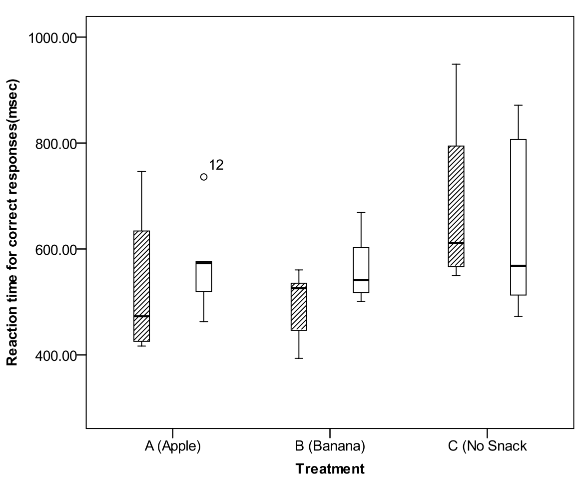
Simple Reaction Time (msec)



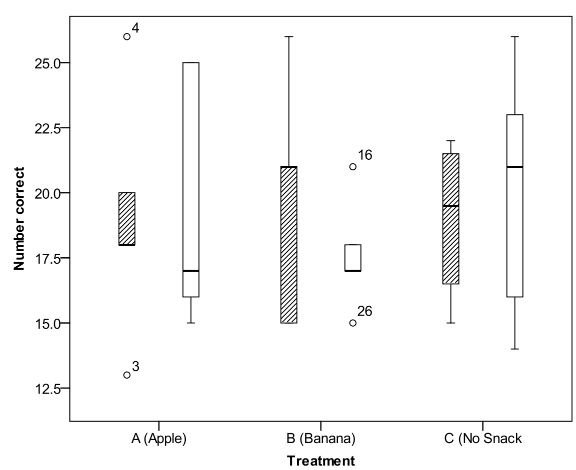
Choice Reaction Time (%)

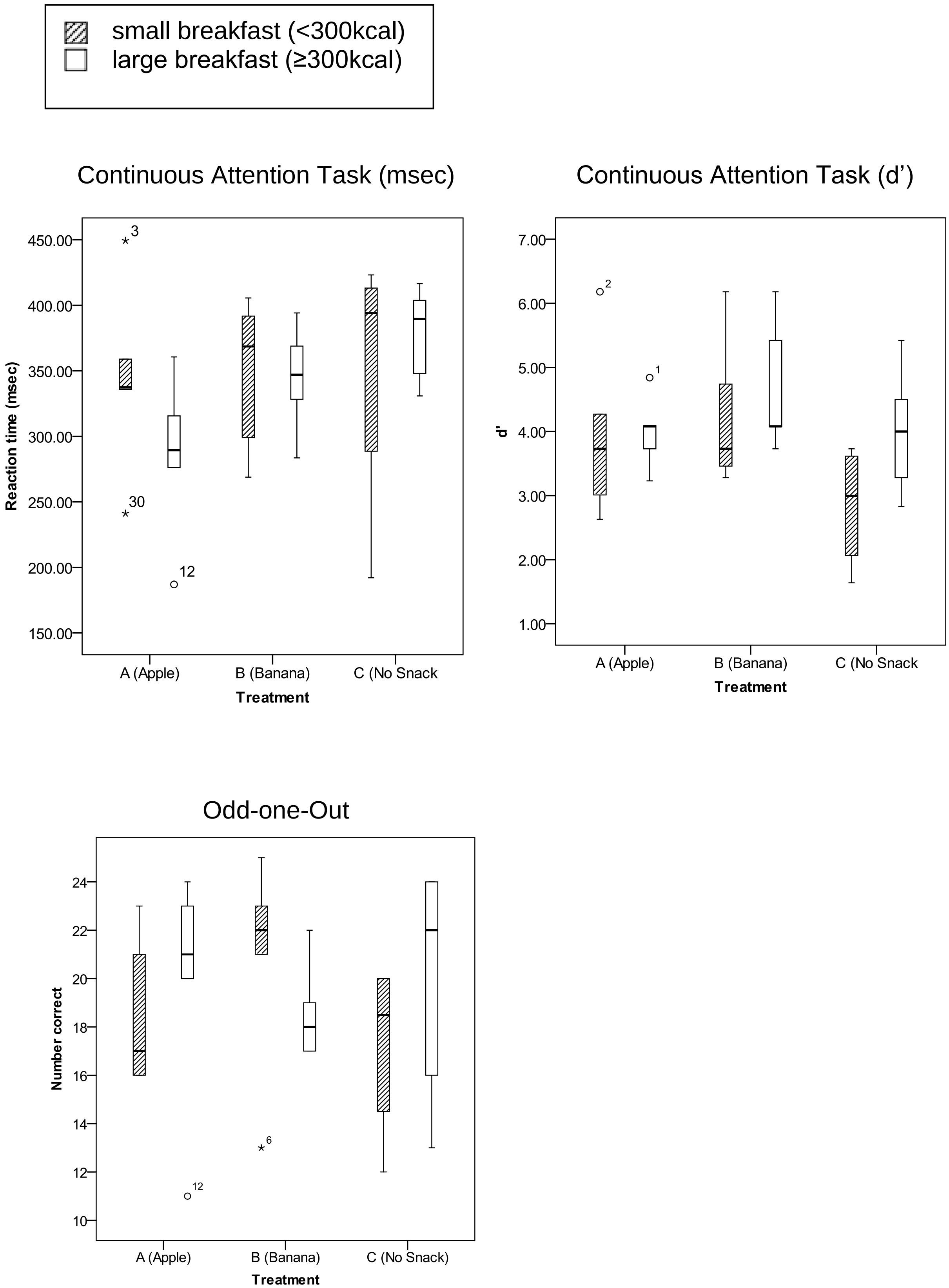


Choice Reaction Time (msec)



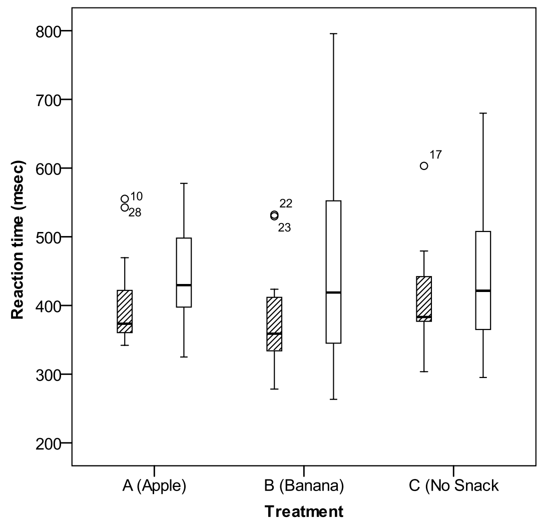
Corsi Blocks



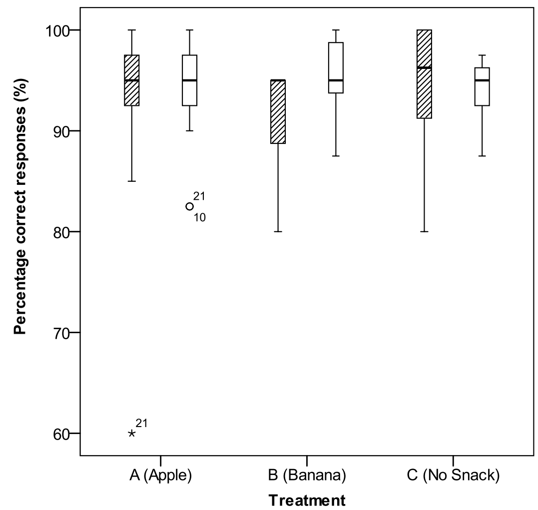

small breakfast (<300kcal)
large breakfast (≥300kcal)
Continuous Attention Task (msec)
Reaction time (msec)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
3
30
12
A (Apple)
B (Banana)
C (No Snack
Treatment
Continuous Attention Task (d')
d'
7.00
6.00
5.00
4.00
3.00
2.00
1.00
2
1
A (Apple)
B (Banana)
C (No Snack
Treatment
Odd-one-Out
Number correct
24
22
20
18
16
14
12
10
12
6
A (Apple)
B (Banana)
C (No Snack)
Treatment

Chapter 3: [assessment time (30, 60 min) x snack (apple, banana, no snack)]. Kcal intake at breakfast as covariate.

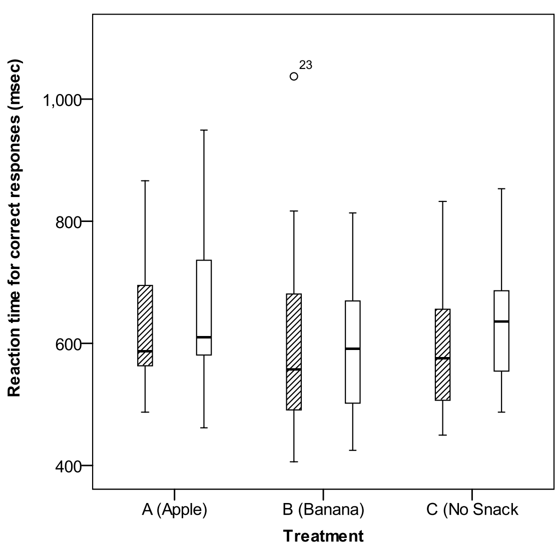
Simple Reaction Time (msec)



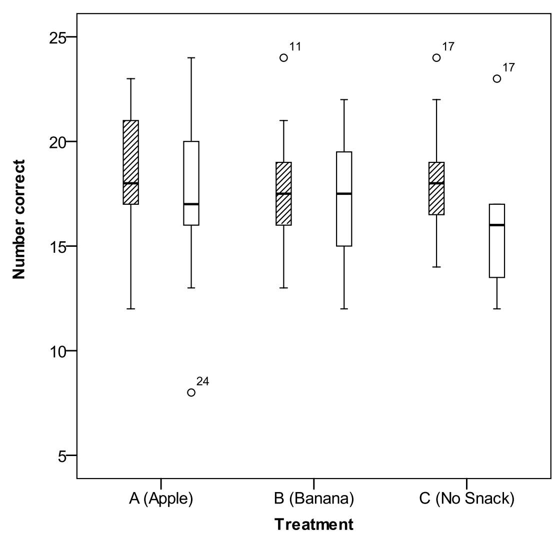
Choice Reaction Time (%)

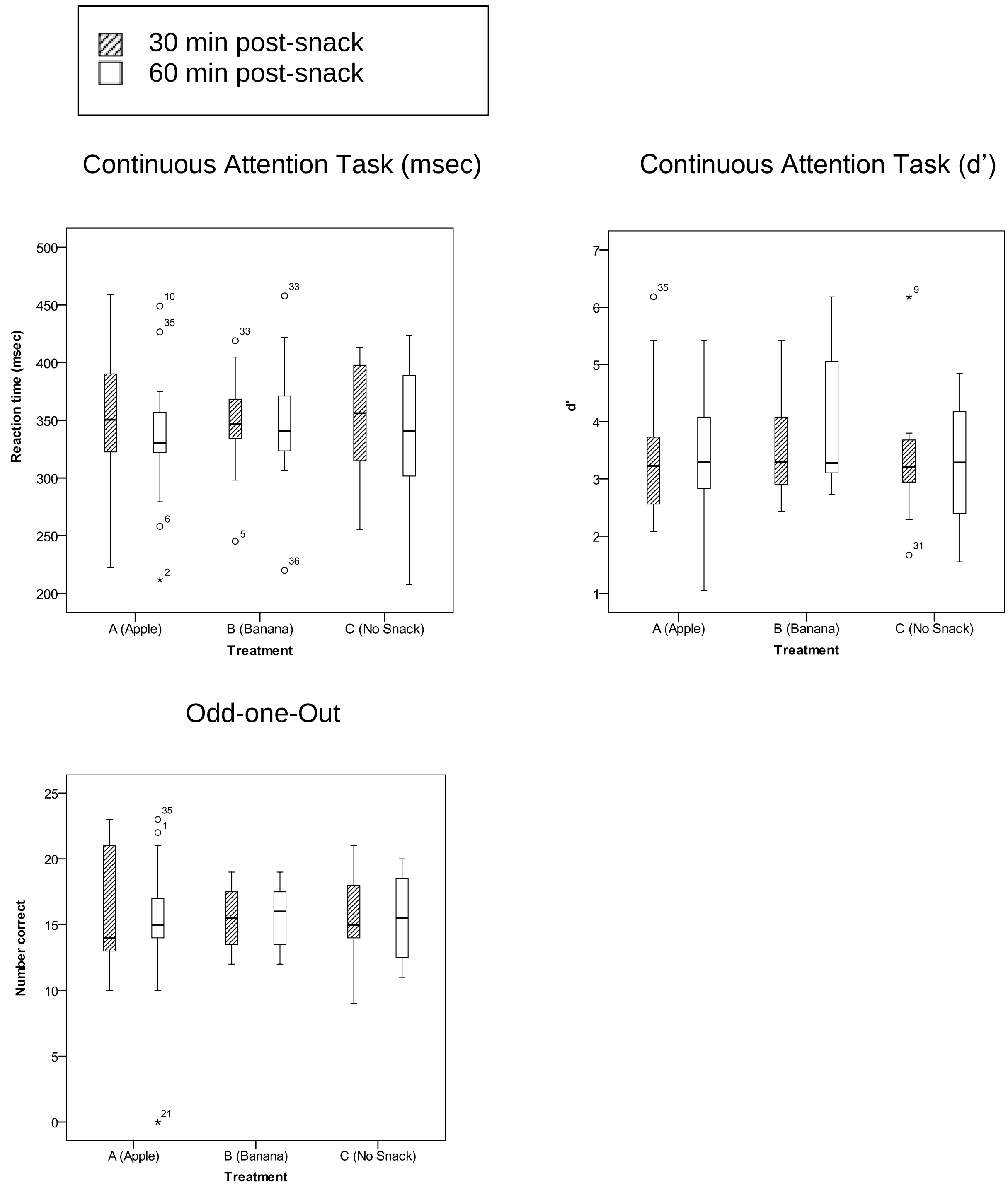


Choice Reaction Time (msec)

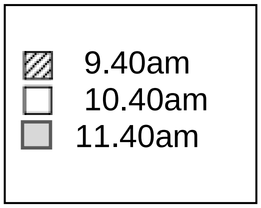


Corsi Blocks

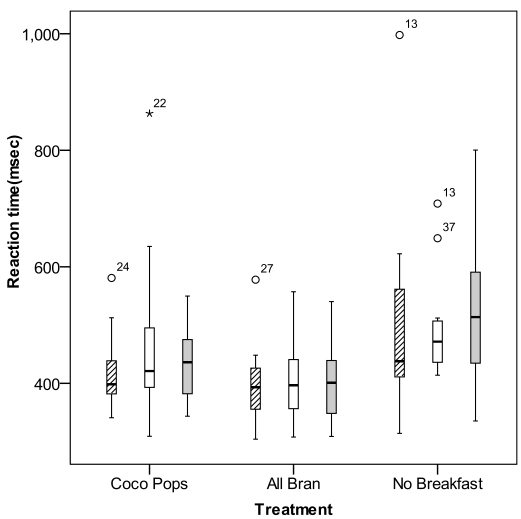



30 min post-snack
60 min post-snack
Continuous Attention Task (msec)
Continuous Attention Task (d')
Reaction time (msec)
d'
Treatment
A (Apple)
B (Banana)
C (No Snack)
Odd-one-Out
Number correct

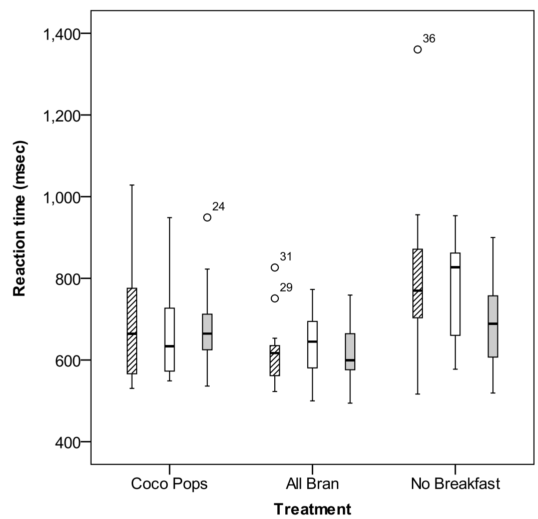
Chapter 4: [assessment time (9.40, 10.40, 11.40) x breakfast (all bran, coco pops, no breakfast)].



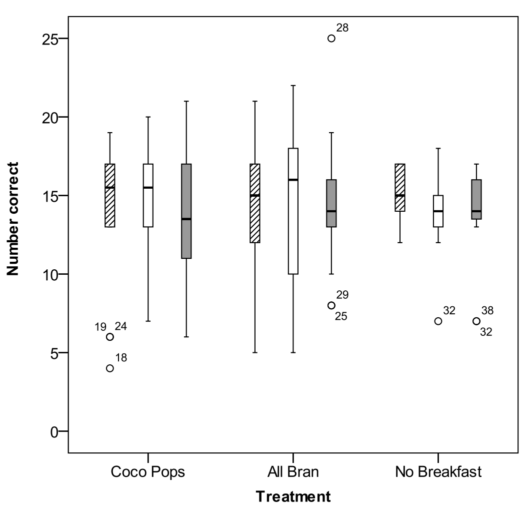
Simple Reaction Time (msec)



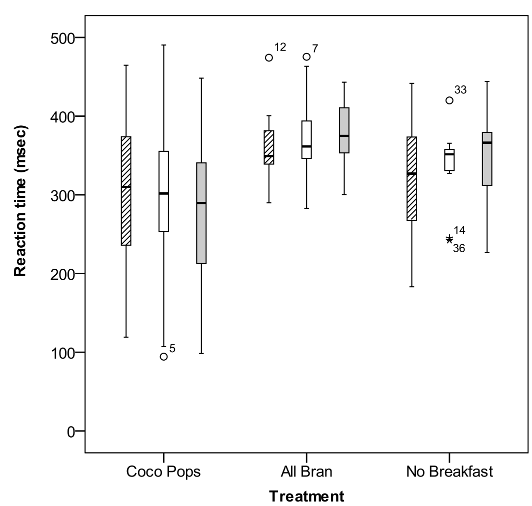
Choice Reaction Time (msec)

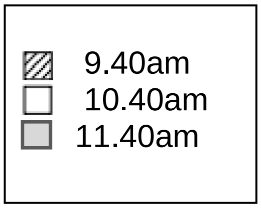


Corsi Blocks

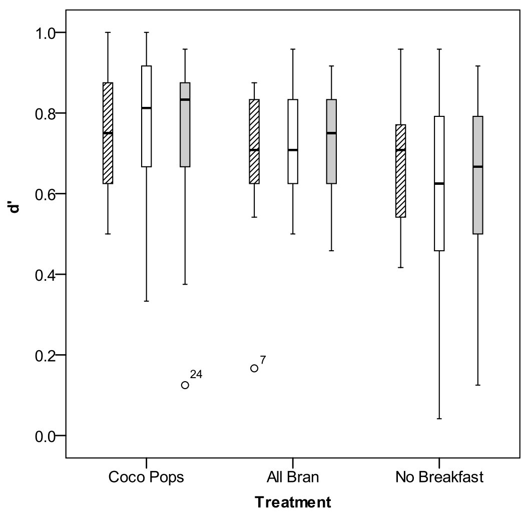


Continuous Attention Task (msec)

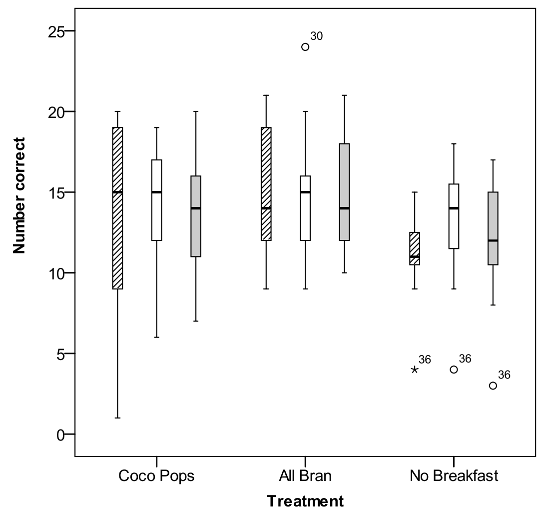




Continuous Attention Task (d')



Odd-one-Out

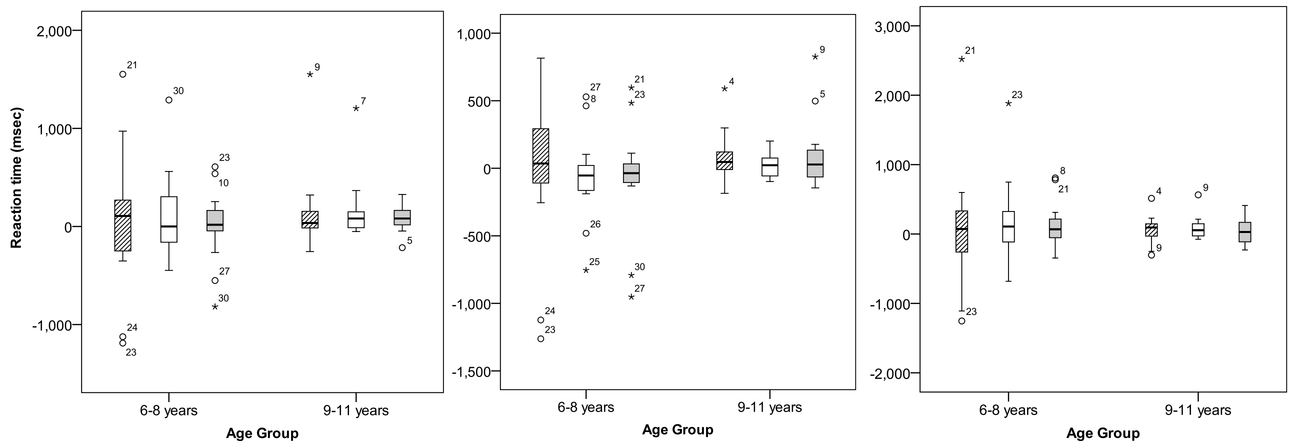


Chapter 5: [breakfast (all bran, coco pops, no breakfast) x assessment time (9.40, 10.40, 11.40) x age (6-8, 9-11)].

Coco Pops
All Bran
No Breakfast

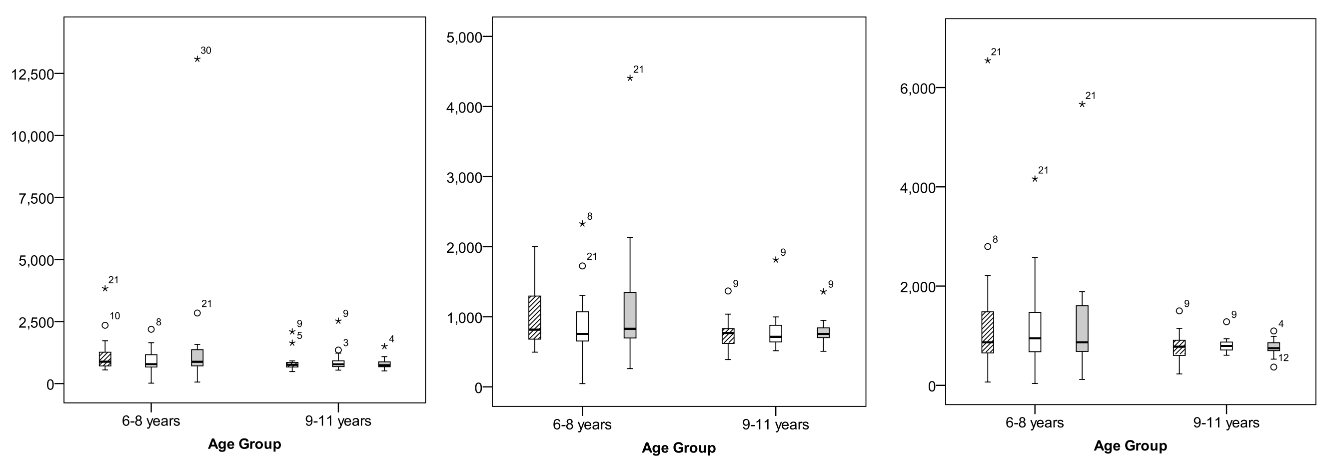
Simple Reaction Time (msec)

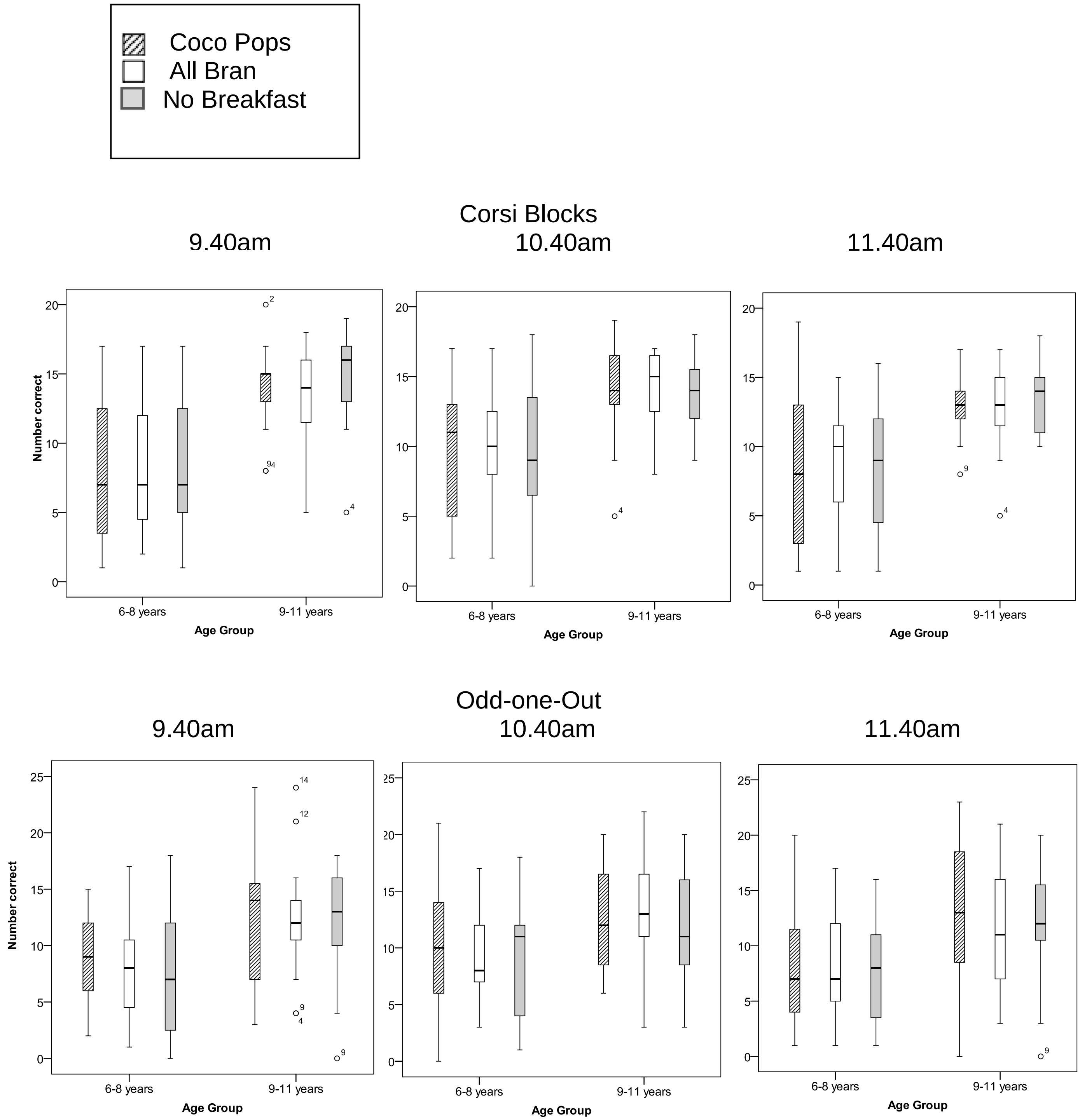
9.40am 10.40am 11.40am



Choice Reaction Time (msec)

9.40am 10.40am 11.40am



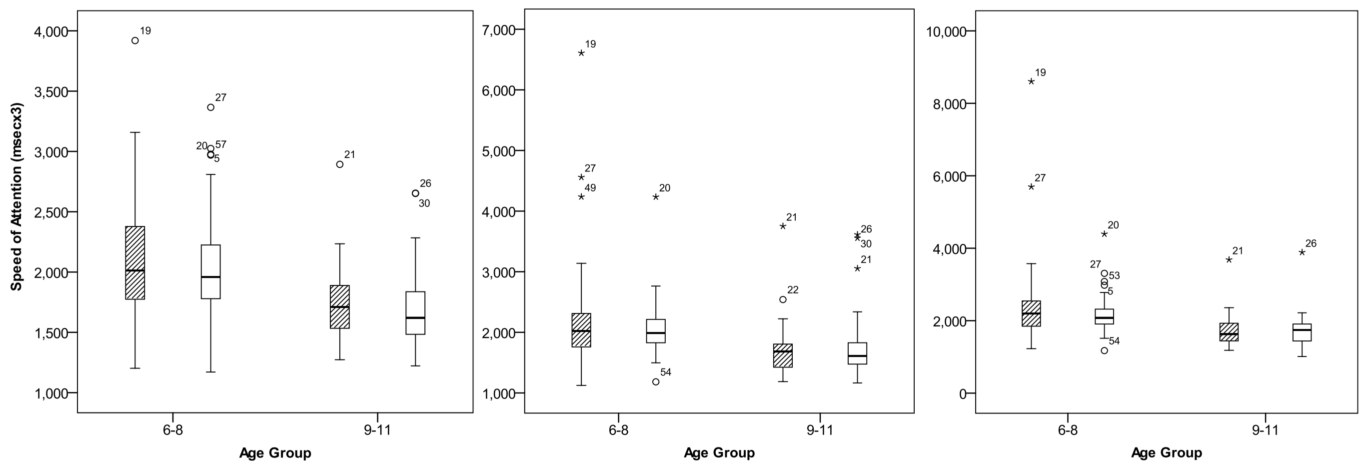

Coco Pops
All Bran
No Breakfast
Corsi Blocks
9.40am
10.40am
11.40am
Odd-one-Out
9.40am
10.40am
11.40am
Number correct
Age Group
6-8 years
9-11 years

Chapter 6: [breakfast (all bran, coco pops) x assessment time (9.40, 10.40, 11.40) x age group (6-8, 9-11)].

Coco Pops
All Bran

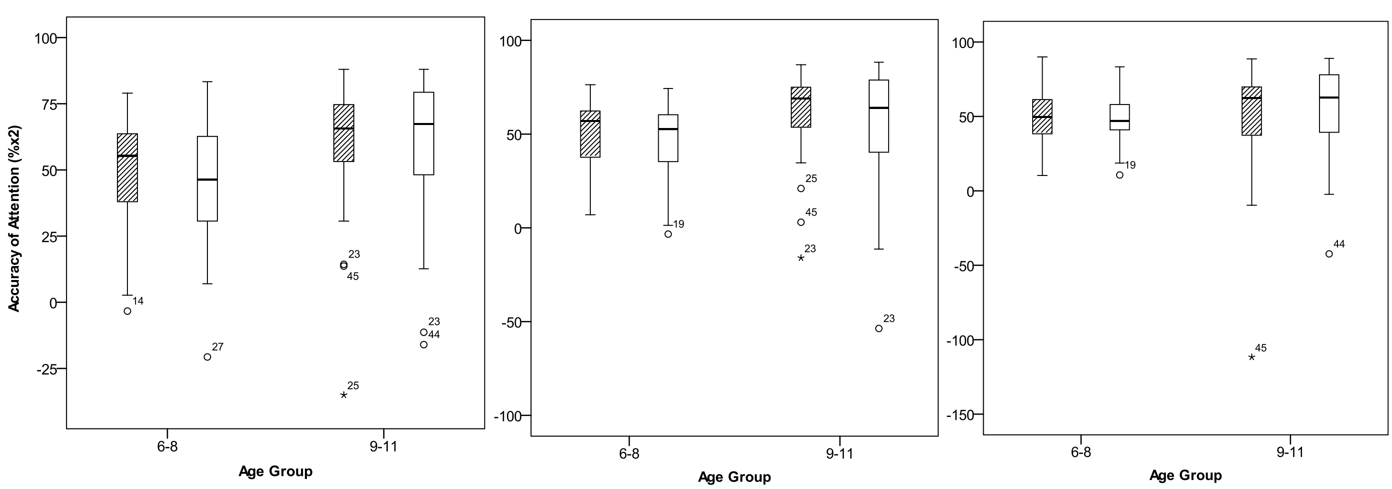
Speed of Attention

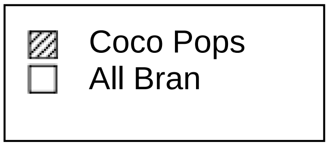
9.40am 10.40am 11.40am



Accuracy of Attention

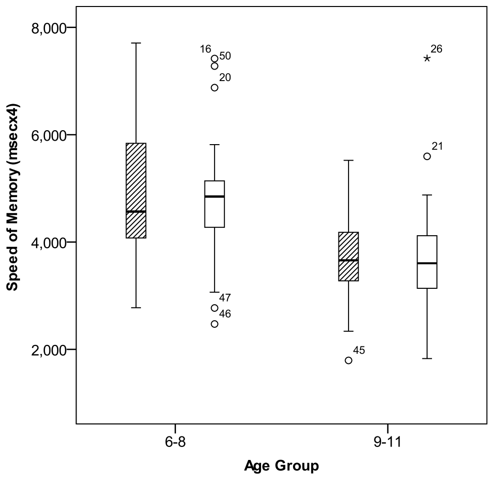
9.40am 10.40am 11.40am



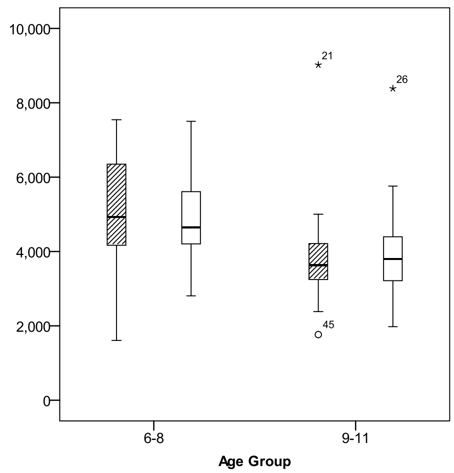


Speed of Memory

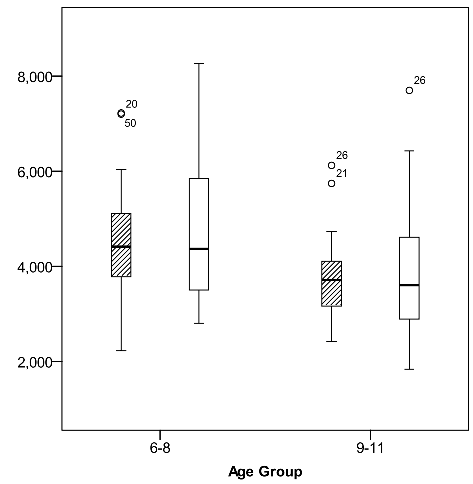
9.40am



10.40am

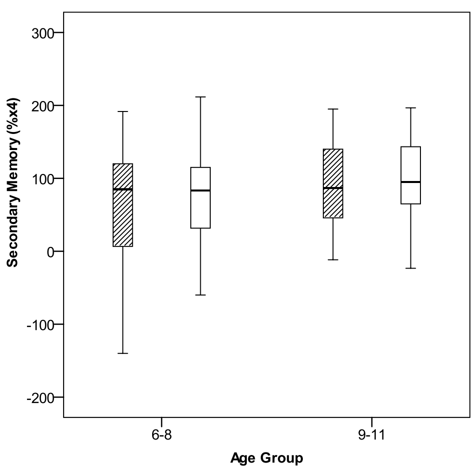


11.40am

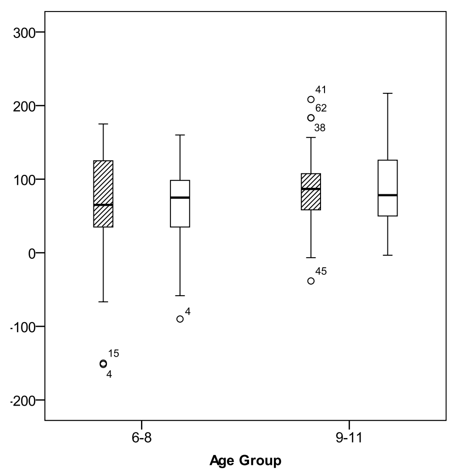


Secondary Memory

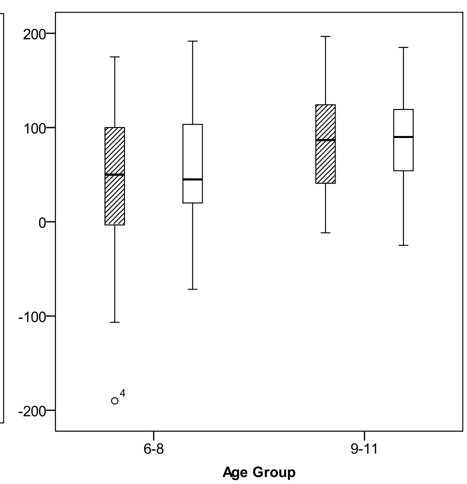
9.40am

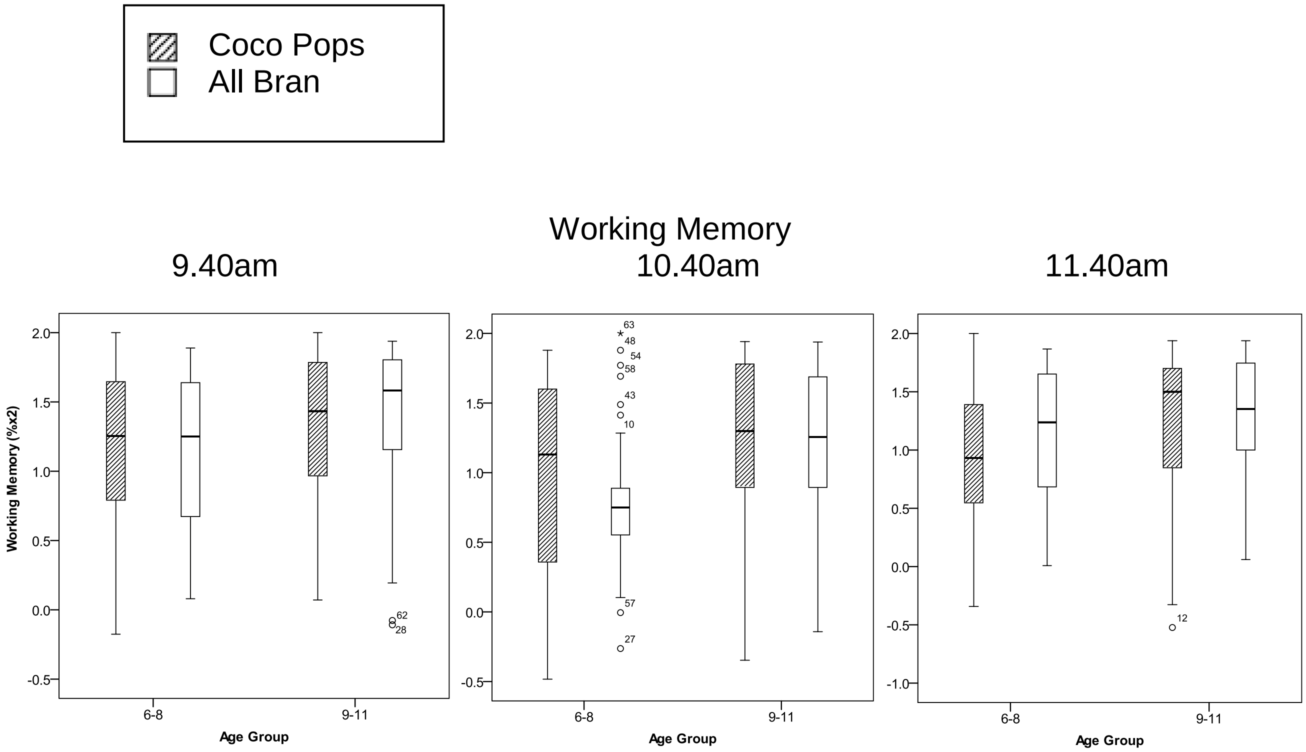


10.40am



11.40am




Coco Pops
All Bran
Working Memory
9.40am
10.40am
11.40am
Working Memory (%x2)
Age Group
6-8
9-11

Appendix 9: Table of F-values for all effects.

Measures	Factors	F-value	p
Chapter 2: [snack (apple, banana, no snack) x breakfast (small, large)]. Cognitive tests at 90 min post-snack.			
Simple Reaction Time	Snack	$F(2,23) = 0.589; p = 0.563$	NS
	Breakfast	$F(1,23) = 0.088; p = 0.769$	NS
	Snack x Breakfast	$F(2,23) = 1.187; p = 0.323$	NS
Choice Reaction Time (%)	Snack	$F(2,24) = 0.340; p = 0.715$	NS
	Breakfast	$F(1,24) = 0.201; p = 0.658$	NS
	Snack x Breakfast	$F(2,24) = 0.102; p = 0.903$	NS
Choice Reaction Time (msec)	Snack	$F(2,24) = 2.608; p = 0.094$	Trend
	Breakfast	$F(1,24) = 0.185; p = 0.671$	NS
	Snack x Breakfast	$F(2,24) = 0.552; p = 0.583$	NS
Corsi Blocks	Snack	$F(2,24) = 0.143; p = 0.868$	NS
	Breakfast	$F(1,24) = 0.003; p = 0.960$	NS
	Snack x Breakfast	$F(2,24) = 0.399; p = 0.676$	NS
Continuous Attention Task (msec)	Snack	$F(2,24) = 1.506; p = 0.242$	NS
	Breakfast	$F(1,24) = 0.206; p = 0.654$	NS
	Snack x Breakfast	$F(2,24) = 1.163; p = 0.329$	NS
Continuous Attention Task (d’)	Snack	$F(2,24) = 2.524; p = 0.101$	NS
	Breakfast	$F(1,24) = 1.946; p = 0.176$	NS
	Snack x Breakfast	$F(2,24) = 0.737; p = 0.489$	NS
Odd-one-Out	Snack	$F(2,24) = 0.145; p = 0.866$	NS
	Breakfast	$F(1,24) = 0.181; p = 0.674$	NS
	Snack x Breakfast	$F(2,24) = 1.002; p = 0.382$	NS
Chapter 3: [assessment time (30, 60 min) x snack (apple, banana, no snack)]. Kcal intake at breakfast as covariate.			
Simple Reaction Time	Snack	$F(2,33) = 0.061; p = 0.941$	NS
	Assessment Time	$F(1,33) = 0.512; p = 0.479$	NS
	Snack x Ass. Time	$F(2,33) = 0.527; p = 0.595$	NS
Choice Reaction Time (%)	Snack	$F(2,33) = 0.163; p = 0.850$	NS
	Assessment Time	$F(1,33) = 0.571; p = 0.455$	NS
	Snack x Ass. Time	$F(2,33) = 0.904; p = 0.415$	NS
Choice Reaction Time (msec)	Snack	$F(2,33) = 0.265; p = 0.768$	NS
	Assessment Time	$F(1,33) = 1.726; p = 0.198$	NS
	Snack x Ass. Time	$F(2,33) = 0.359; p = 0.701$	NS

Appendix 9: Continued.

Measures	Factors	F-value	p
Corsi Blocks	Snack	$F(2,33) = 0.209$; $p = 0.813$	NS
	Assessment Time	$F(1,33) = 0.328$; $p = 0.571$	NS
	Snack x Ass. Time	$F(2,33) = 0.997$; $p = 0.380$	NS
Continuous Attention Task (msec)	Snack	$F(2,33) = 0.015$; $p = 0.985$	NS
	Assessment Time	$F(1,33) = 0.760$; $p = 0.390$	NS
	Snack x Ass. Time	$F(2,33) = 0.338$; $p = 0.716$	NS
Continuous Attention Task (d')	Snack	$F(2,33) = 0.506$; $p = 0.607$	NS
	Assessment Time	$F(1,33) = 1.321$; $p = 0.259$	NS
	Snack x Ass. Time	$F(2,33) = 0.318$; $p = 0.730$	NS
Odd-one-Out	Snack	$F(2,33) = 0.008$; $p = 0.992$	NS
	Assessment Time	$F(1,33) = 6.009$; $p = 0.020$	<0.05
	Snack x Ass. Time	$F(2,33) = 0.268$; $p = 0.767$	NS
Chapter 4: [assessment time (9.40, 10.40, 11.40) x breakfast (all bran, coco pops, no breakfast)].			
Simple Reaction Time	Breakfast	$F(2,35) = 5.110$; $p = 0.594$	NS
	Assessment Time	$F(2,70) = 0.413$; $p = 0.663$	NS
	BF x Ass. Time	$F(4,35) = 742$; $p = 0.567$	NS
Choice Reaction Time (%)	Breakfast	No results due to error	-
	Assessment Time	No results due to error	-
	BF x Ass. Time	No results due to error	-
Choice Reaction Time (msec)	Breakfast	$F(2,35) =0.595$; $p=0.557$	NS
	Assessment Time	$F(2,70) = 3.404$; $p=0.039$	<0.05
	BF x Ass. Time	$F(4,70) = 2.513$; $p=0.049$	<0.05
Corsi Blocks	Breakfast	$F(2,35) = 1.205$; $p=0.312$	NS
	Assessment Time	$F(2,70) = 1.219$; $p=0.302$	NS
	BF x Ass. Time	$F(4,70) = 1.363$; $p=0.256$	NS
Continuous Attention Task (msec)	Breakfast	$F(2,35) = 0.072$; $p = 0.930$	NS
	Assessment Time	$F(2,70) = 0.589$; $p = 0.558$	NS
	BF x Ass. Time	$F(4,70) = 1.357$; $p = 0.258$	NS
Continuous Attention Task (d')	Breakfast	$F(2,35) = 0.623$; $p=0.542$	NS
	Assessment Time	$F(2,70) = 0.308$; $p=0.736$	NS
	BF x Ass. Time	$F(4,70) = 0.626$; $p=0.646$	NS
Odd-one-Out	Breakfast	$F(2,35) = 1.582$; $p=0.217$	NS
	Assessment Time	$F(2,70) = 2.114$; $p=0.128$	NS
	BF x Ass. Time	$F(4,70) = 0.744$; $p=0.565$	NS

Appendix 9: Continued.

Measures	Factors	F-value	p
Chapter 5: [breakfast (all bran, coco pops, no breakfast) x assessment time (9.40, 10.40, 11.40) x age (6-8, 9-11)].			
Simple Reaction Time	Breakfast	$F(2,56) = 1.110$; $p=0.896$	NS
	Assessment Time	$F(2,56) = 3.229$; $p=0.047$	<0.05
	Age	$F(1,28) = 0.263$; $p=0.612$	NS
	BF x Ass. Time	$F(4,112) = 0.644$; $p=0.632$	NS
	BF x Age	$F(2,56) = 0.068$; $p=0.934$	NS
	Ass. Time x Age	$F(2,56) = 2.908$; $p=0.063$	NS
	BF x Ass Time x Age	$F(4,112) = 0.153$; $p=0.962$	NS
Choice Reaction Time (%)	Breakfast	No results due to error	-
	Assessment Time	No results due to error	-
	Age	No results due to error	-
	BF x Ass. Time	No results due to error	-
	BF x Age	No results due to error	-
	Ass. Time x Age	No results due to error	-
	BF x Ass Time x Age	No results due to error	-
Choice Reaction Time (msec)	Breakfast	$F(2,56) = 0.784$; $p=0.462$	NS
	Assessment Time	$F(2,56) = 1.033$; $p=0.362$	NS
	Age	$F(1,28) = 1.448$; $p=0.239$	NS
	BF x Ass. Time	$F(4,112) = 0.441$; $p=0.779$	NS
	BF x Age	$F(2,56) = 1.285$; $p=0.285$	NS
	Ass. Time x Age	$F(2,56) = 0.575$; $p=0.566$	NS
	BF x Ass Time x Age	$F(4,112) = 0.636$; $p=0.638$	NS
Corsi Blocks	Breakfast	$F(2,56) = 0.334$; $p=0.718$	NS
	Assessment Time	$F(2,56) = 4.910$; $p=0.011$	<0.05
	Age	$F(1,28) = 0.826$; $p=0.371$	NS
	BF x Ass. Time	$F(4,112) = 0.491$; $p=0.742$	NS
	BF x Age	$F(2,56) = 0.040$; $p=0.961$	NS
	Ass. Time x Age	$F(2,56) = 2.440$; $p=0.096$	NS
	BF x Ass Time x Age	$F(4,112) = 0.171$; $p=0.953$	NS
Continuous Attention Task (msec)	Breakfast	No results due to error	-
	Assessment Time	No results due to error	-
	Age	No results due to error	-
	BF x Ass. Time	No results due to error	-
	BF x Age	No results due to error	-
	Ass. Time x Age	No results due to error	-
	BF x Ass Time x Age	No results due to error	-
Continuous Attention Task (d')	Breakfast	No results due to error	-
	Assessment Time	No results due to error	-
	Age	No results due to error	-
	BF x Ass. Time	No results due to error	-
	BF x Age	No results due to error	-
	Ass. Time x Age	No results due to error	-
	BF x Ass Time x Age	No results due to error	-

Appendix 9: Continued.

Measures	Factors	F-value	p
Odd-one-Out	Breakfast	$F(2,56) = 0.962; p=0.338$	NS
	Assessment Time	$F(2,56) = 6.761; p=0.002$	<0.005
	Age	$F(1,28) = 1.424; p=0.243$	NS
	BF x Ass. Time	$F(4,112) = 0.151; p=0.962$	NS
	BF x Age	$F(2,56) = 0.434; p=0.650$	NS
	Ass. Time x Age	$F(2,56) = 0.132; p=0.128$	NS
	BF x Ass Time x Age	$F(4,112) = 0.789; p=0.535$	NS
<u>Chapter 6:</u> [breakfast (all bran, coco pops) x assessment time (9.40, 10.40, 11.40) x age group (6-8, 9-11)].			
Speed of Attention	Breakfast	$F(2,62) = 1.035; p = 0.313$	NS
	Assessment Time	$F(1.78, 110.92) = 6.125; p = 0.004$	<0.005
	Age	$F(2,62) = 5.936; p = 0.018$	<0.05
	BF x Ass. Time	$F(2,124) = 1.082; p=0.342$	NS
	BF x Age	$F(1,62) = 2.277; p=0.136$	NS
	Ass. Time x Age	$F(1.78, 110.92) = 3.681; p = 0.028$	<0.05
	BF x Ass Time x Age	$F(2,124) = 2.786; p=0.066$	NS
Accuracy of Attention	Breakfast	$F(1,62) = 1.31; p = 0.256$	NS
	Assessment Time	$F(2,124) = 2.329; p = 0.102$	NS
	Age	$F(1,62) = 4.98; p = 0.029$	<0.05
	BF x Ass. Time	$F(1.90,117.96) = 3.614; p = 0.032$	<0.05
	BF x Age	$F(1,62) = 1.765; p=0.189$	NS
	Ass. Time x Age	$F(2,124)= 2.588; p=0.079$	NS
	BF x Ass Time x Age	$F(2,124) = 1.583; p=0.209$	NS
Speed of Memory	Breakfast	$F(1,62) = 1.127; p = 0.293$	NS
	Assessment Time	$F(2,124) = 4.185.; p = 0.017$	<0.05
	Age	$F(2,62) = 4.954; p = 0.030$	<0.05
	BF x Ass. Time	$F(2,124) = 1.861; p=0.160$	NS
	BF x Age	$F(1,62) = 0.026; p=0.872$	NS
	Ass. Time x Age	$F(2,124) = 1.411; p=0.248$	NS
	BF x Ass Time x Age	$F(2,124) = 0.949; p=0.390$	NS
Secondary Memory	Breakfast	$F(1,62) = 5.479; p = 0.022$	<0.05
	Assessment Time	$F(2,124) = 7.718; p = 0.001$	<0.005
	Age	$F(1,62) = 0.205; p = 0.652$	NS
	BF x Ass. Time	$F(2,124) = 0.150; p=0.861$	NS
	BF x Age	$F(1,62) = 0.588; p=0.446$	NS
	Ass. Time x Age	$F(2,124) = 1.789; p=0.171$	NS
	BF x Ass Time x Age	$F(2,124) = 0.399; p=0.672$	NS
Working Memory	Breakfast	$F(1,62) = 0.210; p = 0.648$	NS
	Assessment Time	$F(2,124) = 10.228; p = 0.00008$	<0.0001
	Age	$F(1,62) = 1.584; p = 0.213$	NS
	BF x Ass. Time	$F(2,124) = 1.984; p=0.142$	NS
	BF x Age	$F(1,62) = 0.071; p=0.791$	NS
	Ass. Time x Age	$F(2,124) = 1.235; p=0.294$	NS
	BF x Ass Time x Age	$F(2,124) = 0.919; p=0.402$	NS

Appendix 10: Alternative Results for Breakfast Studies (ANCOVA with baseline scores as covariate)

Chapter 4: [assessment time (9.40, 10.40, 11.40) x breakfast (all bran, coco pops, no breakfast)].

4.8. Results

Mean scores on baseline and each assessment time are presented in Table 4.4.

4.8.1. Simple Reaction Time

There were no significant main effects of Assessment Time ($F(2,68) = 0.401$; $p=0.671$) or Breakfast ($F(2,34) = 1.010$; $p=0.375$) or any significant interaction ($F(4,68) = 0.853$; $p=0.497$).

4.8.2. Choice Reaction Time

4.8.2.1. Percentage correct responses

An error occurred in the recording of the percentage correct responses and hence, no results are presented for this measure.

Table 4.4: Mean scores (SD) on baseline and at each assessment time for each breakfast condition.

Measure	Condition	Baseline	9.40 am	10.40 am	11.40 am
Simple RT (msec)	Coco Pops	414.37 (56.51)	419.65 (67.00)	470.50 (137.80)	439.80 (62.91)
	All Bran	392.21 (52.86)	402.04 (67.51)	400.27 (69.35)	402.80 (62.91)
	No Break	472.80 (88.40)	507.70 (186.09)	501.32 (94.63)	520.35 (129.30)
	Total	423.70 (72.38)	443.13 (18.67)	457.37 (17.30)	454.31 (14.28)
Choice RT (msec for correct responses)	Coco Pops	674.79 (91.49)	688.04 (139.31)	680.58 (134.89)	683.63 (102.66)
	All Bran	627.98 (73.67)	621.54 (84.81)	637.27(81.52)	615.97 (74.72)
	No Break	786.14 (213.98)	814.33 (220.11)	763.62 (126.65)	700.70 (121.69)
	Total	691.01 (145.81)	707.97 (25.00)	693.82(19.03)	666.77 (16.35)
Corsi Blocks (no. correct)	Coco Pops	15.36 (3.99)	13.86 (4.92)	14.86 (3.74)	13.57 (4.30)
	All Bran	13.69 (4.87)	14.54 (4.37)	14.23 (5.24)	14.31 (4.55)
	No Break	14.18 (2.18)	15.09(1.81)	13.73 (2.80)	13.55 (3.45)
	Total	14.45 (3.89)	14.50 (0.66)	14.27 (0.67)	13.81 (0.68)
Continuous Attention (RT msec))	Coco Pops	284.62 (135.24)	296.66 (101.82)	295.81 (113.31)	279.37 (100.90)
	All Bran	371.36 (56.43)	361.86 (44.78)	372.10 (55.96)	376.25 (40.47)
	No Break	323.87 (116.65)	323.24 (80.26)	336.61 (51.67)	348.08 (57.96)
	Total	325.66 (111.84)	327.25 (13.02)	334.84 (13.25)	334.56 (11.87)
Continuous Attention (d')	Coco Pops	0.55 (0.53)	0.76 (0.17)	0.76 (0.19)	0.74 (0.23)
	All Bran	0.65 (0.19)	0.69 (0.19)	0.72 (0.15)	0.71 (0.16)
	No Break	0.44 (0.51)	0.67 (0.16)	0.57 (0.29)	0.60 (0.27)
	Total	0.56 (0.43)	0.71 (0.03)	0.69 (0.04)	0.68 (0.404)
Odd-one-Out Recall (no. correct)	Coco Pops	12.71 (3.52)	13.00 (6.08)	13.93 (4.38)	13.14 (4.07)
	All Bran	14.15 (3.63)	14.85 (4.08)	14.77 (4.15)	14.15 (3.72)
	No Break	11.27 (3.13)	10.91 (2.81)	13.09 (4.01)	11.82 (4.02)
	Total	12.79 (3.55)	12.92 (0.76)	13.93 (0.68)	13.04 (0.64)

4.8.2.2. Reaction time for correct responses

Analysis revealed a significant main effect of Assessment Time ($F(2,68) = 9.136$; $p=0.0003$). Pairwise comparisons showed a significant difference between 9.40am and 11.40am ($p=0.024$) with better performance at 11.40am (664.22 msec) than at 9.40am (702.90 msec) (Fig. 4.1). Pairwise comparisons showed no other significant differences.

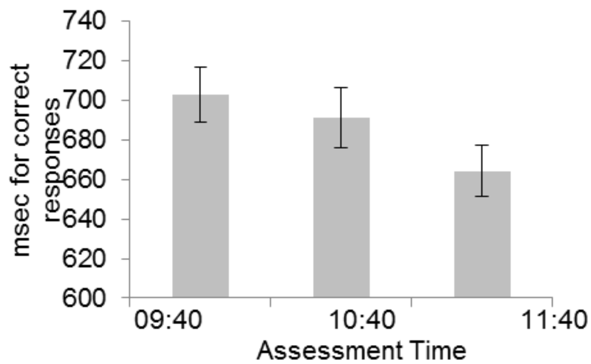


Fig. 4.1: Main effect of assessment time on reaction time scores for the choice reaction time test.

There was no significant main effect of Breakfast ($F(2,34) =0.678$; $p=0.514$) or interaction ($F(4,68) = 0.835$; $p=0.508$).

4.8.3. Corsi Blocks

Analysis showed no significant main effect of Assessment Time ($F(2,68) = 0.584$; $p=0.560$) or Breakfast ($F(2,34) = 0.639$; $p=0.534$) or any significant interaction effect ($F(4,68) = 1.349$; $p=0.261$).

4.8.4. Continuous Attention Task

4.8.4.1. Reaction time for correct responses

There were no significant effects of breakfast ($F(2,34) = 1.768$; $p = 0.186$) or interaction ($F(4,68) = 1.800$; $p = 0.139$). There was however, a significant main effect of assessment time ($F(2,68) = 3.422$; $p = 0.038$). Pairwise comparisons did however, not reveal any further significant differences between the test times.

4.8.4.2. d'

Analysis revealed no significant main effects of Assessment Time ($F(2,68) = 0.353$; $p=0.704$) or Breakfast ($F(2,34) = 2.386$; $p=0.107$) or significant interaction ($F(4,68) = 0.595$; $p=0.668$).

4.8.5. Odd-one-Out

The results showed no significant main effects of Assessment Time ($F(2,68) = 0.003$; $p=0.997$) or Breakfast ($F(2,34) = 0.062$; $p=0.940$) or significant interaction ($F(4,68) = 0.748$; $p=0.563$).

Appendix 10: Continued

<u>Chapter 5:</u> [breakfast (all bran, coco pops, no breakfast) x assessment time (9.40, 10.40, 11.40) x age (6-8, 9-11)].

5.3. Results

Mean scores on baseline and for each time point are presented in Table 5.3. Unfortunately an error occurred during the recording of the Choice RT Test (correct responses) and the Continuous Attention Task test so no results are reported for these tests. Due to the number of interactions in the current study, interactions are only reported if significant.

5.3.1. Simple Reaction Time

Analysis showed no significant main effects of Breakfast ($F(2,50) = 0.307$; $p=0.737$), Age Group ($F(1,25) = 0.481$; $p=0.495$) or main effect of Assessment Time ($F(2,50) = 1.087$; $p=0.345$).

5.3.2. Choice Reaction Time

5.3.2.1. Percentage correct responses

An error occurred in the recording of the percentage correct responses and hence, no results are presented for this measure.

Table 5.3: Mean scores (SD) on baseline and at each assessment time for each breakfast condition by age group.

Measure	Breakfast	Age Groups	n	Baseline	9.40am	10.40am	11.40am
Simple RT (msec)	Coco Pops	6-8yrs	15	671.71 (452.70)	702.09 (589.59)	669.17 (472.63)	749.84 (756.24)
		9-11yrs	15	510.26 (206.08)	656.36 (605.72)	590.01 (324.38)	572.91 (208.96)
	All Bran	6-8yrs	15	509.77 (212.66)	634.30 (459.21)	454.17 (285.12)	712.25 (611.37)
		9-11yrs	15	476.08 (106.49)	636.11 (365.84)	496.86 (139.90)	564.70 (205.38)
	No Breakfast	6-8yrs	15	519.68 (292.79)	535.22 (308.90)	450.99 (283.04)	638.53 (343.13)
		9-11yrs	15	454.61 (125.80)	544.14 (147.95)	547.20 (328.58)	495.47 (181.68)
	Total		30		618.04 (53.96)	534.73 (47.19)	622.28 (61.87)
Choice RT (msec for correct responses)	Coco Pops	6-8yrs	15	1043.80 (544.96)	1197.58 (879.78)	1034.76 (486.52)	1424.09 (1579.84)
		9-11yrs	15	699.47 (145.45)	879.94 (426.51)	758.08 (234.40)	796.88 (305.20)
	All Bran	6-8yrs	15	863.50 (296.13)	927.66 (535.80)	926.82 (542.70)	1250.86 (1047.78)
		9-11yrs	15	789.81 (223.57)	937.33 (492.59)	813.05 (314.04)	813.14 (162.83)
	No Breakfast	6-8yrs	15	993.28 (585.81)	1796.18 (3189.17)	1191.65 (1021.13)	1303.93 (1324.12)
		9-11yrs	15	734.83 (163.83)	811.70 (240.05)	791.35 (192.84)	765.48 (179.73)
	Total		30		1091.73 (156.78)	919.28 (81.91)	1059.06 (166.25)
Corsi Blocks (no. correct)	Coco Pops	6-8yrs	15	10.87 (3.18)	8.33 (5.29)	9.60 (5.05)	8.40 (5.59)
		9-11yrs	15	15.07 (2.25)	14.07 (3.22)	13.93 (3.86)	13.87 (2.26)
	All Bran	6-8yrs	15	10.47 (4.66)	8.27 (4.76)	9.67 (3.72)	8..80 (3.98)
		9-11yrs	15	14.20 (3.30)	13.27 (3.41)	13.87 (3.27)	12.93 (3.37)
	No Breakfast	6-8yrs	15	10.33 (4.29)	8.53 (4.91)	9.67 (3.71)	8.20 (4.86)
		9-11yrs	15	15.13 (2.72)	14.67 (3.66)	13.87 (2.67)	13.27 (2.46
	Total		30		11.19 (0.684)	11.767 (0.626)	10.74 (0.614)
Odd-one-Out Recall (no. correct)	Coco Pops	6-8yrs	15	14.33 (6.03)	11.80 (5.39)	12.73 (7.01)	10.93 (6.04)
		9-11yrs	15	20.07 (6.82)	16.80 (6.46)	17.53 (5.30)	17.40 (8.26)
	All Bran	6-8yrs	15	12.80 (4.90)	11.20 (5.70)	12.68 (4.12)	11.40 (6.02)
		9-11yrs	15	18.80 (6.05)	16.73 (6.10)	17.60 (6.50)	15.13 (6.36)
	No Breakfast	6-8yrs	15	13.33 (6.59)	10.60 (7.65)	12.20 (6.90)	10.33 (5.68)
		9-11yrs	15	17.07 (7.42)	16.20 (5.68)	15.73 (6.35)	16.07 (7.00)
	Total		30		13.89 (0.973)	14.74 (1.00)	13.54 (1.06)

5.3.2.2. Reaction time for correct responses

The results showed no significant main effects of Assessment Time ($F(2,50) = 1.258$; $p=0.293$), Breakfast ($F(2,50) = 0.122$; $p=0.886$) or Age Group ($F(1, 25) = 0.444$; $p=0.511$).

5.3.3. Corsi Blocks

Analysis showed no significant main effect of Assessment Time ($F(2,50) = 0.086$; $p=0.918$), Breakfast ($F(2,50) = 0.295$; p=0.0.746) or Age Group ($F(1,25) = 0.004$; $p=0.953$).

5.3.4. Continuous Attention Task

5.3.4.1. Reaction time for correct responses

During the recording of the percentage correct responses and error occurred, hence, no results are presented for this measure.

5.3.4.2. d’

An error occurred in the recording of the percentage correct responses so there are no results to report for this measure.

5.3.5. Odd-one-Out

The results revealed no significant main effects of Breakfast ($F(2,50) = 0.545$ $p=0.583$), Age Group ($F(1,25) = 0.015$; $p=0.904$) or Assessment Time ($F(2,50) = 0.973$; $p=0.385$).

Appendix 10: Continued

<u>Chapter 6:</u> [breakfast (all bran, coco pops) x assessment time (9.40, 10.40, 11.40) x age group (6-8, 9-11)].

6.3. Results

Mean scores on baseline and for each assessment time are presented in Table 6.3.

6.3.1. Speed of Attention

The results showed no significant main effect of Breakfast ($F(1,60) = 0.301$; $p = 0.585$), Age Group ($F(1,60) = 1.114$; $p = 0.296$) or Assessment Time ($F(1.799, 107.924) = 0.981$; $p = 0.371$, following Huynh-Feldt correction).

Table 6.3: Mean scores (SD) on baseline and at each assessment time for each breakfast condition by age group.

Measure	Breakfast	Age Group	n	Baseline	9.40 am	10.40 am	11.40 am
Speed of Attention (msec x 3)	Coco Pops	6-8yrs	29	1785.77 (284.21)	2124.64 (551.23)	2317.77 (1096.84)	2569.17 (1440.32)
		9-11yrs	35	1538.37 (226.37)	1737.29 (318.36)	1720.09 (461.80)	1734.41 (451.34)
	All Bran	6-8yrs	29	1788.39 (303.65)	2094.06 (510.42)	2123.76 (545.97)	2208.63 (631.62)
		9-11yrs	35	1511.39 (231.73)	1697.65 (351.20)	1755.60 (566.80)	1772.93 (466.07)
		Total	64				
Accuracy of Attention (% x 2)	Coco Pops	6-8yrs	29	56.77 (17.77)	49.51 (20.27)	50.11 (17.09)	48.49 (17.93)
		9-11yrs	35	67.71 (17.49)	60.06 (25.44)	61.28 (22.91)	48.69 (37.11)
	All Bran	6-8yrs	29	49.06 (28.30)	45.14 (25.55)	47.12 (21.11)	47.62 (17.19)
		9-11yrs	35	68.32 (17.07)	58.51 (27.40)	56.09 (30.47)	56.16 (28.81)
		Total	64				
Speed of Memory (msec x 4)	Coco Pops	6-8yrs	29	4802.56 (1072.15)	5026.25 (1382.44)	4974.74 (1506.85)	4510.99 (1173.93)
		9-11yrs	35	4024.22 (682.03)	3777.75 (805.00)	3794.16 (1168.37)	3708.28 (847.68)
	All Bran	6-8yrs	29	4679.40 (1216.61)	4717.06 (1212.53)	4965.30 (1253.10)	4759.00 (1590.62)
		9-11yrs	35	3946.12 (968.61)	3761.63 (957)	3906.70 (1229.89)	3783.63 (1284.96)
		Total	64				
Secondary Memory (% x 4)	Coco Pops	6-8yrs	29	96.66 (71.83)	59.99 (84.10)	57.46 (82.21)	35.63 (83.66)
		9-11yrs	35	136.23 (48.65)	93.66 (57.60)	86.66 (50.47)	84.99 (52.60)
	All Bran	6-8yrs	29	100.80 (58.57)	76.49 (67.80)	65.39 (56.33)	55.11 (67.34)
		9-11yrs	35	119.33 (63.85)	97.37 (55.45)	91.47 (58.64)	87.99 (51.75)
		Total	64				
Working Memory (% x 2)	Coco Pops	6-8yrs	29	1.04 (0.54)	1.17 (0.62)	0.95 (0.73)	0.96 (0.62)
		9-11yrs	35	1.32 (0.49)	1.32 (0.55)	1.23 (0.62)	1.23 (0.63)
	All Bran	6-8yrs	29	1.06 (0.59)	1.16 (0.56)	0.82 (0.56)	1.12 (0.51)
		9-11yrs	35	1.42 (0.46)	1.38 (0.56)	1.21 (0.53)	1.28 (0.50)
		Total	64				

6.3.2. Accuracy of Attention

Analysis revealed no significant main effects of Breakfast ($F(1,60) = 0.598$; p = 0.442), Age Group ($F(1,60) = 3.382$; p = 0.071) or Assessment Time ($F(2,120)$ = 0.848; p = 0.431). The analysis showed a significant interaction between Assessment Time and Breakfast ($F(2,120) = 5.452$; p = 0.005) (Fig. 6.1). Further repeated measures ANOVAs were carried out to check for differences between the High (Coco Pops) and Low (All Bran) at each Assessment Time point. Analyses revealed no significant differences at 9.40am ($F(1,60) = 0.821$; p = 0.369) or 10.40am (F(1,630 = 0.052; p = 0.811). There was however, a significant differences between performance following the High and the Low GI breakfasts at 11.40am ($F(1,60) = 6.413$; p = 0.014) with better performance after the Low GI (52.59) than the High GI breakfast (49.28) suggesting that the interaction between Assessment Time and Breakfast was the result of a sharp decline in performance at 11.40am following the consumption of the High GI cereal Coco Pops.

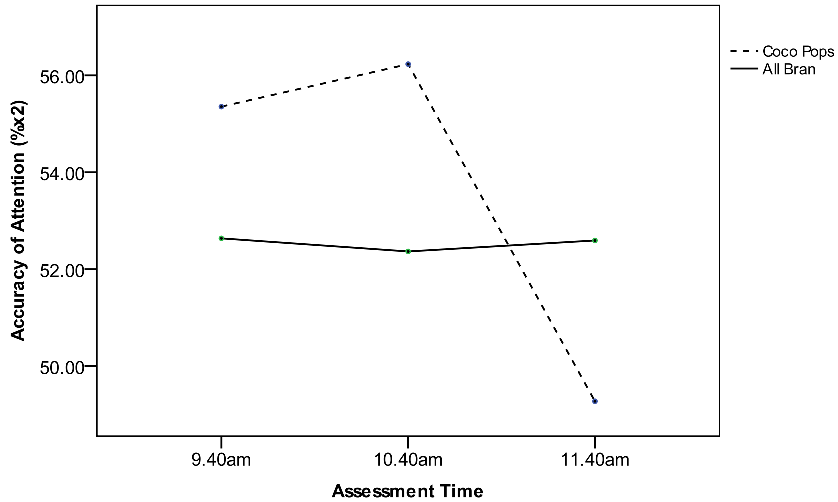


Figure 6.1: Scores at each Assessment Time on Accuracy of Attention following Coco Pops (High GI) and All Bran (Low GI).

6.3.3. Speed of Memory

Analysis on Speed of Memory showed no significant main effect of Breakfast ($F(1,60) = 0.744$; $p = 0.392$) or Assessment Time ($F(2,120) = 0.029.$; $p = 0.0.972$). There was however, a main effect of Age Group ($F(1,60) = 4.141$; $p = 0.046$) with better performance for the older children (4129.04) than the younger children (4414.79) (Fig. 6.2).

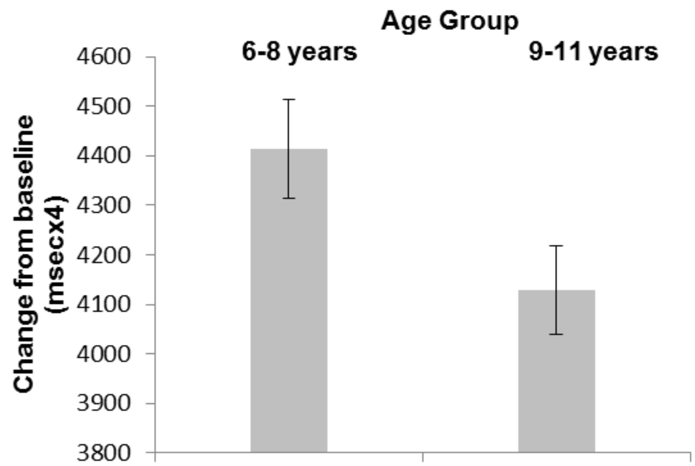


Figure 6.2: Main effect of age on the speed of memory factor.

6.3.4. Secondary Memory

Analyses revealed no significant main effect of Age Group ($F(1,60) = 0.232$; $p = 0.632$) or Assessment Time ($F(2,120) = 0.920$; $p = 0.401$).

There was however, a significant main effect of Breakfast ($F(1,60) = 6.999$; $p = 0.010$) with better performance following All Bran (low GI) (80.03) than Coco Pops (high GI) (71.37) (Fig. 6.3).

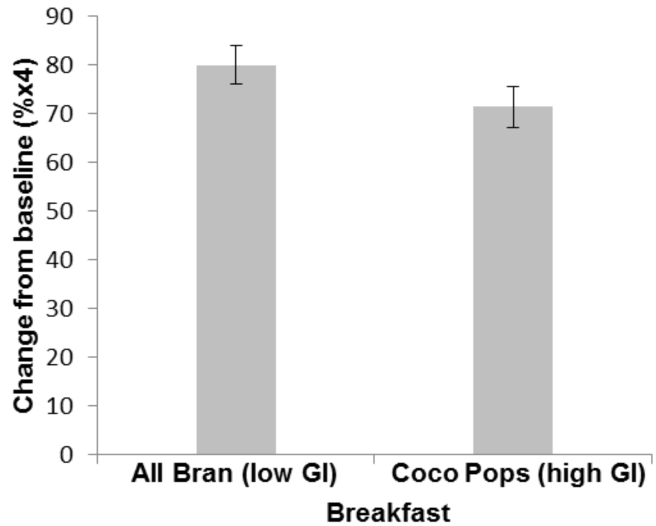


Figure 6.3: Main effect of breakfast on the secondary memory factor.

6.3.5. Working Memory

There was no significant effect of Breakfast (F(1,59) = 0.0.118; p = 0.732), Age Group (*F*(1,59) = 0.385; *p* = 0.537) or Assessment Time (*F*(1.893,111,682) = 2.555; *p* = 0.085, following Huynh-Feldt correction). There was however, a significant interaction between assessment Time and Age Group (*F*(2,118) = 3.350; *p* = 0.038) (Fig. 6.4). To further examine the interaction further repeated measures ANOVAs were carried out to check for differences between the Age Groups at each Assessment Time. Analysis showed no significant differences between the age groups at 9.40am (*F*(1,59) = 0.522; *p* = 0.473), 10.40am (*F*(1,60) = 3.798; *p*= 0.056) or 11.40am (*F*(1,60) = 0.003; *p* = 0.957).

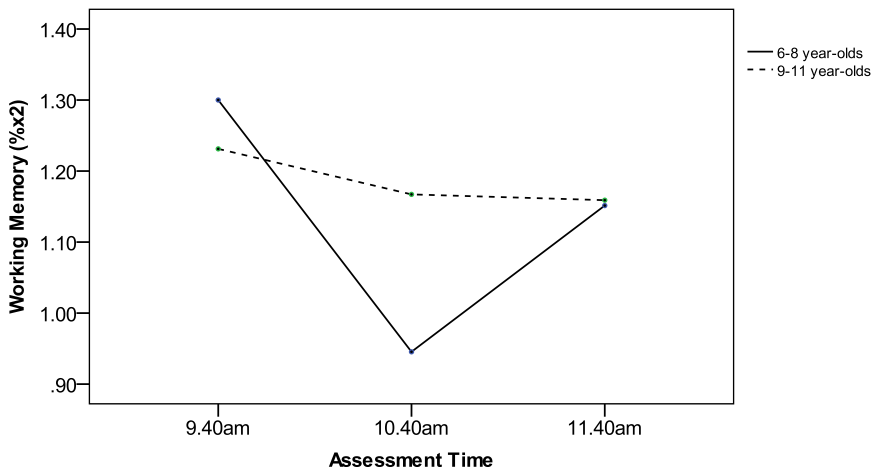


Figure 6.4: Scores at each Assessment Time for each Age Group on Working Memory.

The results also showed a significant interaction between Assessment Time and Breakfast (F(2,118) = 4.575; p = 0.012) (Fig. 6.5). To elucidate the interaction further repeated measures ANOVAs were carried out to check for differences between the High (Coco Pops) and Low (All Bran) at each Assessment Time point. Analyses revealed no significant differences at 9.40am (F(1,59) = 0.723; p = 0.399) or 11.40am (F(1,60) = 2.449; p = 0.123). There was however, a significant difference at 10.40am (F(1,60) = 4.375; p = 0.041) with better performance after the. Coco Pops (high GI) (1.10) than after All Bran (low GI) (1.03).

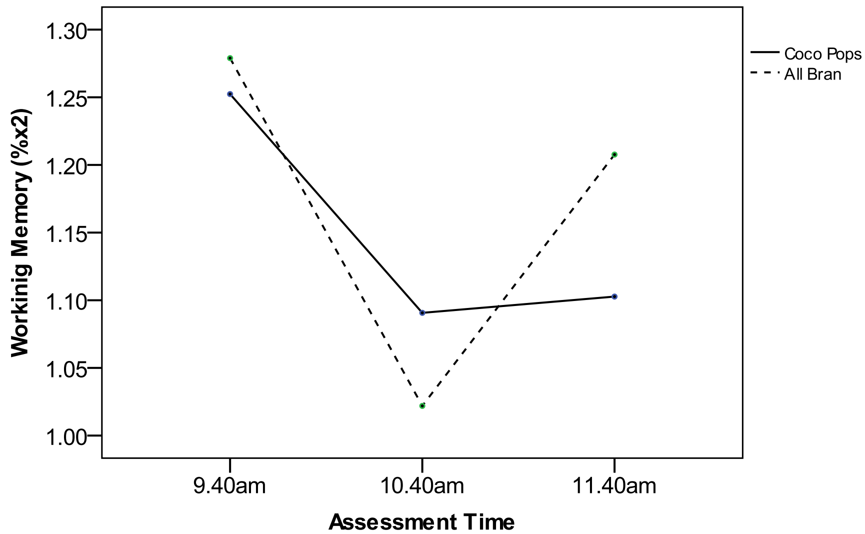


Figure 6.5: Scores at each Assessment Time for each Breakfast on Working Memory.

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